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PHYSICS.—*Exploring the fundamentals of aerodynamics.*[1]

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The selection of a topic for a presidential address before such a general scientific organization as the Washington Academy of Sciences has offered some difficulty. One has the choice of attempting some broad philosophical discussion of science in relation to society, military affairs, or the Government, of setting forth the contributions of his own specialized field of science to human welfare as a means of justifying on practical grounds its claims to support by society, or of simply describing the present status and challenging problems of his specialized field in extending the frontiers of human knowledge. I have elected to follow this last plan, since I could add but little to the many excellent discussions of the broader relations of science which are found both in our own past proceedings and in the scientific press of today and since I feel that the constant harping on immediate practical applications hampers the development of basic scientific knowledge. The matters of which I will speak do have applications not only to improving the performance of aircraft, its most publicized application, but also to such diverse fields as improving the performance of power plants, improving processes such as drying, mixing, and evaporation used in the manufacture of many useful materials, improving ventilation of buildings and many others. But I prefer to uphold the somewhat old-fashioned view that advances in pure science need no justification by immediately evident practical applications. Like a program of conservation of forests, soil, or other natural resources, the practical benefits lie in the future and can not be fully foretold. For some reason our national characteristics are such as to lessen our enthusiasm for such investments.

In spite of the fact that the war has monopolized the time of all scientists and in particular physicists and aerodynamicists, there has been substantial progress in our understanding of the fundamentals of the motion of air. During the war even this type of material was classified as confidential or secret, but now, fortunately, these classifications have been removed. Some of the work described in this account was done at the National Bureau of Standards with the cooperation of the National Advisory Committee for Aeronautics. Like many scientists I find myself with the passing of years occupied more and more with administration and less and less with the active day-to-day direction of experimental work. Therefore I wish specially to emphasize that the experimental work was directed by G. B. Schubauer and carried out with the collaboration of H. K. Skramstad, P. S. Klebanoff, and W. Squire.

The student of air motion learns to recognize certain recurring typical situations in the great multiplicity of naturally occurring and experimental situations and to understand complicated phenomena as an assembly of these idealized typical situations. This procedure is nothing but the familiar scientific method of isolating certain aspects of natural phenomena, reconstructing idealized and simplified versions for experimental study, and of attempting to understand these simplified situations.

The first of these typical situations is that present near the surface of the forward portion of a body moving through the air. No matter how fast the body moves, the air

[1] Address of the retiring president of the Washington Academy of Sciences. Read by title at the meeting of the Academy on February 20, 1947. Received February 28, 1947.

immediately in contact with the surface is at rest relative to the surface, i.e., is carried along with the speed of the body. At a considerable distance the air is at rest if there is no natural wind. It is convenient to observe the motion from the standpoint of an observer on the moving body, i.e., to consider the equivalent case of flow around a fixed object placed in a moving air stream. At speeds less than the speed of sound the presence of the object causes the oncoming air to slow up directly in front of the object and to be deflected around it. As the air moves around the object its speed increases above the free stream speed. These effects extend to distances comparable with the dimensions of the object, but their magnitudes are greatest near the body. The resulting field of flow around the forward part of the object corresponds fairly well to that predicted from the theory of a fluid without friction except in a thin film very close to the surface. Here the speed falls rapidly to zero at the surface, the rate of change with distance normal to the surface being several times greater than in the flow outside. This relatively thin layer, known as the boundary layer, was first observed by L. Prandtl, of the University of Göttingen, about 40 years ago. It is produced by the action of the viscosity of the air. Prandtl developed the mathematical theory of the flow in a boundary layer starting with the long established Navier-Stokes equations for the motion of a viscous fluid.

The thickness of the boundary layer depends on the size of the object and its speed through the fluid as well as on the viscosity of the fluid, the thickness at any point for geometrically similar bodies being proportional to the square root of viscosity times a linear dimension divided by the speed. The actual thickness for a particular case is shown in Fig. 1. Here the object is a long elliptical cylinder of about 4 inches by 12 inches cross section in an air stream of 60 and 70 feet per second. The thickness is only a few hundredths of an inch at the nose and is considerably less than 0.1 inch over the entire front portion.

Beginning about 25 years ago it has been possible to study the distribution of speed and the character of the motion within boundary layers. The instruments used are extremely small probes made of hypodermic tubing for measuring the pressures produced by the flow or extremely fine wires heated electrically whose rate of cooling is a measure of the air speed. The mechanics of the flow within the boundary layer has proved to be the key to the understanding of many aerodynamic phenomena.

It was soon discovered, first by Prandtl from indirect evidence such as skin friction

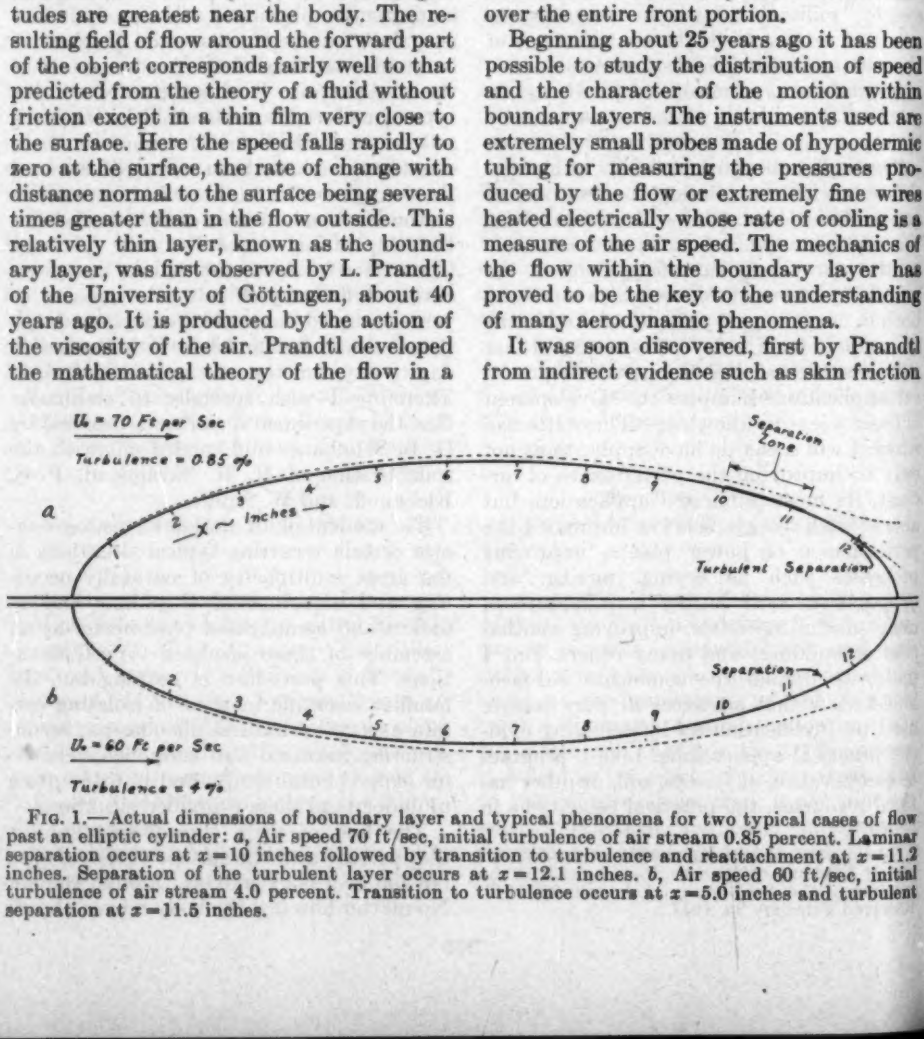

FIG. 1.—Actual dimensions of boundary layer and typical phenomena for two typical cases of flow past an elliptic cylinder: *a*, Air speed 70 ft/sec, initial turbulence of air stream 0.85 percent. Laminar separation occurs at $x = 10$ inches followed by transition to turbulence and reattachment at $x = 11.2$ inches. Separation of the turbulent layer occurs at $x = 12.1$ inches. *b*, Air speed 60 ft/sec, initial turbulence of air stream 4.0 percent. Transition to turbulence occurs at $x = 5.0$ inches and turbulent separation at $x = 11.5$ inches.

measurements and later confirmed by others by direct measurement of speed distribution, that the flow in a boundary layer does not always correspond to that described by the Navier Stokes equations, a flow that is commonly called laminar since it may be considered to occur in thin laminae that slide over each other with only the friction associated with the viscosity. The flow is often turbulent, another concept long familiar to hydraulic engineers. A precise definition of turbulent flow is somewhat technical, but as in the case of many concepts hard to define in words, every layman is familiar with the phenomena described. He has surely observed the smoke from a cigarette in a quiet room rising smoothly in layers, the motion described as laminar. At some distance above the cigarette, however, unless the air in the room is extraordinarily quiet, this smooth motion breaks up into a confused series of whirls and eddies, a motion described as turbulent. One characteristic of turbulent motion is the presence of random speed fluctuations superposed on the mean flow. The isolation of these concepts of two kinds of flow, the development of more precise descriptions, and the recognition of the two types in various parts of the flow field aided greatly in understanding more clearly what went on and why in complicated flow fields.

One striking difference in regions of laminar and turbulent flow in boundary layers is the great increase in skin friction when the flow becomes turbulent or conversely the very low skin friction which is obtained if the boundary layer flow can be maintained in the laminar state. During the war the Germans captured one of our Mustang aircraft and measured its performance. They were astounded. To quote from one of their reports: "There has been much discussion of the question of the Mustang wing. The comparison of flight measurements, however, shows quite unmistakably that the Mustang is far superior aerodynamically to all other airplanes and that it maintains this superiority in spite of its considerably greater wing area."

The Mustang wing was of the general type first developed by E. N. Jacobs and his colleagues of the National Advisory Committee for Aeronautics in the years just prior to the war, a type known as laminar flow wings. These wings are so designed as to maintain the flow in the boundary layer laminar over the greatest practicable area of the wing surface, a result accomplished as will be discussed later by designing the wing section so that the pressure on the surface continually falls from its maximum value at the nose for as great a distance from the nose as practicable. (See Fig. 2.) The resulting drag of the wing at the design lift is about one-half that of a conventional wing for which the boundary layer flow is turbulent except near the nose. The low drag region is limited to a certain range of lift coefficient as shown in Fig. 3.

The development of these wings was made possible by fundamental studies of the character of flow in the air streams produced in wind tunnels and improvements in wind-tunnel design carried out by the NACA and by the National Bureau of Standards. The low drag occurring in flight is not observed in ordinary wind tunnels, for in a wind tunnel it is difficult to eliminate completely the turbulent motion arising from the blades of the wind-tunnel fan, the guide vanes at the corners, and the wall of the wind-tunnel upstream from the model. The presence of this turbulence makes it impossible to maintain the boundary layer flow laminar for any considerable distance.

The residual turbulence in an air stream can be described in part by the root-mean-square values of the speed fluctuation. Even though the turbulent fluctuations amount to less than 1 per cent of the mean speed, they produce large effects on the boundary layer flow; in particular the transition from laminar to turbulent motion is controlled by the turbulence present. In free flight the turbulence is substantially zero. Hence there has been great interest in the effects of turbulence in wind tunnel measurements and in the reduction of turbulence in wind tunnels.

It is only recently that methods have been developed for decreasing the turbulence of an air stream. This "smoothing" of an air stream is somewhat analogous to

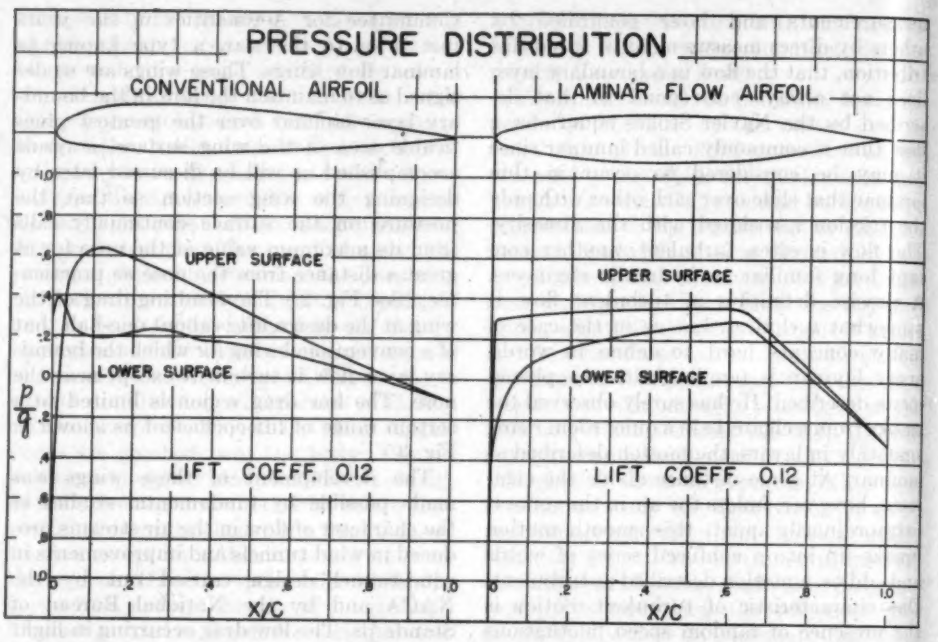

FIG. 2.—Pressure distribution on conventional and laminar flow airfoils: x = distance from leading edge, C = chord length, p = the pressure referred to the static pressure of the undisturbed flow, q = the velocity pressure, which is the product of one-half the air density by the square of the air speed. Note that reduced pressures are plotted upward, and that the distributions are for the same lift.

FIG. 3.—Drag coefficients for conventional and laminar flow airfoils.

the "smoothing" of a rough metal surface. To smooth a rough casting one uses a coarse file or rasp which itself has a rough surface. The rasp actually roughens the surface but with a finer scale than the gross irregularities that it "smooths." By repeating with surfaces of ever finer scales of roughness down to a fine emery cloth, a surface of the desired smoothness is obtained. An air stream is smoothed by the use of wire screens, which remove turbulence of large scale and introduce some of smaller scale. Small-scale turbulence decays rapidly, and if the wires of the screen are sufficiently fine they produce no turbulence. Ordinary wind tunnels have speed fluctuations in the range 0.5 to 1.0 per cent of the mean speed; low-turbulence wind tunnels have been built with fluctuations reduced to the order of 0.02 to 0.05 per cent of the mean speed.

In ordinary wind tunnels it has been observed that the boundary layer near the nose of a body is laminar even when turbulent fluctuations are present if the state of flow is judged by the character of the mean speed distribution. A closer examination shows that there are irregular velocity fluctuations present excited by the stream turbulence and of the character of fluctuations in thickness of the boundary layer. The laminar state continues to a distance from the nose, which is controlled by the amount and scale of the turbulence present, higher stream turbulence causing transition to turbulent flow at a point nearer the nose. G. I. Taylor gave a theory of this effect some time ago and it is fairly well understood.

When the turbulence of the air stream is extremely low, a different phenomenon is observed—regular laminar boundary layer oscillations. The development of wind tunnels of low turbulence in fact made possible a complete understanding of the processes leading to the transition of the flow in the boundary layer from the laminar to the turbulent state. The history of this advance illustrates the international character of science. About 15 years ago W. Tollmien, of Göttingen, published a mathematical theory of the stability of the laminar motion in the boundary layer near a thin flat plate in an air stream flowing parallel to the plate. According to this theory small disturbances of wavelength lying in a certain region would be amplified, whereas disturbances of shorter or longer wavelength would be damped. The wavelength range and limits are functions of the Reynolds number, the name given to the ratio of the product of the speed of the air stream by the boundary layer thickness to the kinematic viscosity of the air. The calculations were repeated and extended by H. Schlichting in 1933. In 1935 my colleagues and I at the National Bureau of Standards under the sponsorship of the NACA studied the flow near a flat plate experimentally and failed to find any evidence of the development of the amplified disturbances described by Tollmien and Schlichting. Experiments at the California Institute of Technology, the Massachusetts Institute of Technology, and Cambridge University, England, likewise failed to show the amplified disturbances. All these investigations were made in ordinary wind tunnels.

In 1940 when a wind tunnel of extremely low turbulence was available, my colleagues G. B. Schubauer and H. K. Skramstad repeated the earlier experiment and in August 1940 obtained records of the velocity fluctuations in the boundary layer of a flat plate by means of a hot wire anemometer as shown in Fig. 4. The frequency of these spontaneously occurring almost-sinusoidal oscillations agreed very well with the value predicted by the Tollmien-Schlichting theory. Their amplitude increased downstream until turbulent motion ensued, at first intermittently and then continuously. It was clear that the oscillations were not observed in the earlier experiments because of the controlling effect of wind tunnel turbulence.

Schubauer and Skramstad devised an ingenious method of introducing controlled small disturbances of known frequency as illustrated in Fig. 5. The disturbances were produced by vibrating a very thin (0.002 inch) flat ribbon whose mean position was about 0.006 inch from the plate. A magnetic field was produced in the vicinity of the ribbon by electromagnets on the opposite side of the plate, and an alternating

current of the desired frequency passed through the ribbon. The amplitude of the disturbance could be controlled by varying the current. The ensuing fluctuations of speed in the boundary layer were measured by a hot wire anemometer. Frequency, damping, and wavelength could be independently measured.

After this experimental work had been completed, C. C. Lin, a Chinese student at the California Institute of Technology, undertook a revision of the mathematical theory of the stability of two-dimensional parallel flows and a clarification of some features of the Tollmien-Schlichting theory which had been adversely criticized. Lin made a brief report to the National Academy of Sciences (Proceedings, October 1944) and published a complete account in the Quarterly of Applied Mathematics, vol. 3, pp. 117–142, 218–234, 277–301. Lin's calculation gave slightly different results from those published by Tollmien and Schlichting.

Fig. 6 shows the experimental values of the wavelengths of disturbances which are neither damped nor amplified corresponding to the Reynolds numbers indicated, as compared with the theoretical curves of Lin and Schlichting. Disturbances lying within the open loop are amplified; those outside it are damped. For Reynolds numbers below 420, disturbances of all wavelengths are damped. The agreement between theory and experiment is remarkable and similar agreement is found for the independently determined frequency locus.

In the free atmosphere the initial dis-

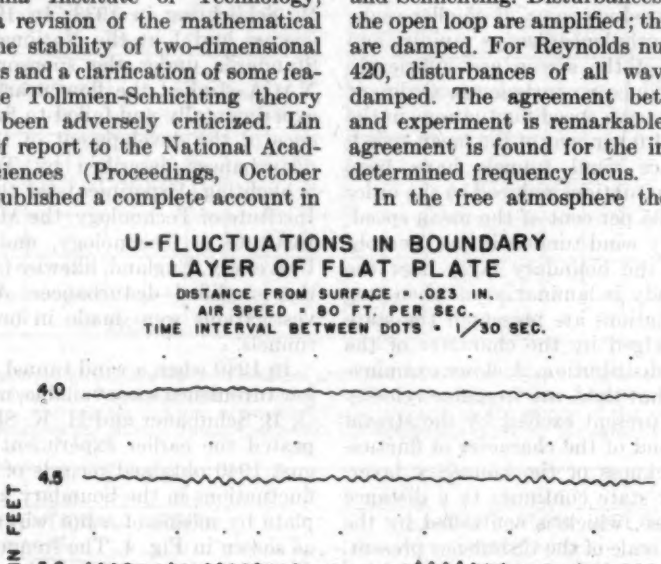

FIG. 4.—Laminar boundary layer oscillations near a flat plate.

turbances may be the sound waves from the engine or propeller. It has been shown by Schubauer and Skramstad that excitation by intense sound waves does in fact produce earlier transition from laminar to turbulent flow, i.e., nearer the leading edge of the plate.

This contribution to aerodynamics is the result of work by German, English, American, and Chinese scientists.

Theoretical computations of the stability of boundary layers subjected to pressure gradients were made by German scientists during the war, and a limited amount of experimental work has been done in this country. As previously mentioned, a falling pressure in the downstream direction greatly increases the stability, the critical Reynolds number being much larger than for the case of uniform pressure. Similarly, a rising pressure makes the laminar flow much more unstable and reduces the critical Reynolds number.

J. Ackeret and his colleagues at the Zurich Aerodynamic Institute have demonstrated that the transition from laminar to turbulent flow in the boundary layer can be prevented by removing a part of the boundary layer by sucking air into the interior of the body through slots or through a porous surface. He was, in fact, able to restore a turbulent boundary layer to the laminar condition. By careful attention to the detailed design of the internal ducting of the suction system he has obtained extremely low drag coefficients. These results are also in conformity with stability calculations made by German investigators.

H. W. Liepmann at the California Institute of Technology studied the effect of the curvature of the surface on the stability of laminar flow. He observed the laminar boundary layer oscillations of the Tollmien-Schlichting type on the convex side of a curved plate, using the oscillating ribbon technique of Schubauer and Skramstad as well as artificial regular roughness of variable wavelength and acoustic excitation. The results agreed closely with those obtained at the National Bureau of Standards, the influence of convex curvature being extremely small. Hence transition on the upper surface of a wing will not be noticeably affected by the curvature of the surface.

For concave surfaces a boundary layer of small thickness (ratio of momentum thickness to radius of curvature less than 0.00005) also exhibits instability of the same type due to Tollmien-Schlichting waves. For boundary layers of large thickness (ratio of momentum thickness to radius of curvature greater than 0.0005) the instability is associated with three-dimensional disturbances of the type predicted and observed by G. I. Taylor for flow between rotating cylinders and studied theoretically by Görtler for boundary layer flow. For intermediate values of the thickness there is a gradual change from one type of instability to the other.

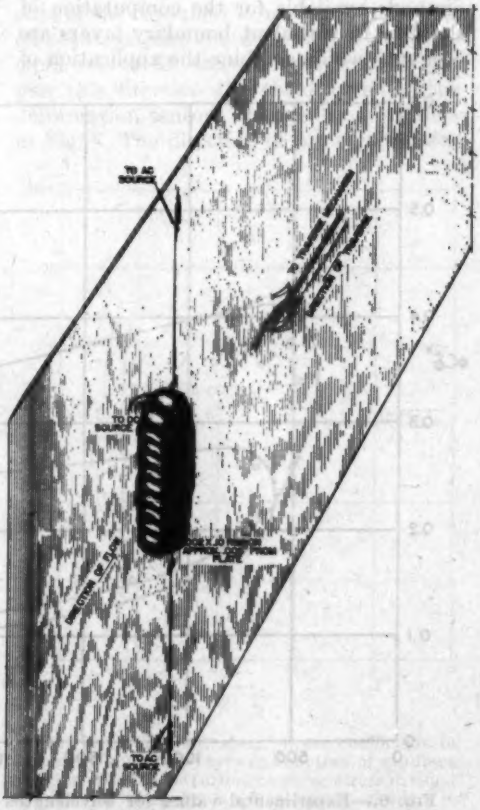

FIG. 5.—Apparatus for producing controlled disturbances in a laminar boundary layer.

The mechamism of the instability of the laminar boundary layer is now quite clear. Small disturbances are always present arising from surface roughness, noise, or stream turbulence, and these will have a certain spectral distribution of energy. The disturbances are selectively amplified by the boundary layer until large sinusoidal oscillations are present. These grow in amplitude, become distorted, and finally produce turbulent motion by a process whose details are not yet fully understood. If initial disturbances are large enough, the required amplification is small and transition is dependent mainly on their magnitude.

Let us now turn our attention to the turbulent boundary layer. Progress in understanding the mechanics of turbulent flow has been slow. Practically all of the methods available for the computation of the flow in turbulent boundary layers are of a type which combine the application of the momentum principle with empirical relations obtained from a few experimental studies. Such developments are of importance to the practical engineer but they do not satisfy one who tries to understand the basic phenomena.

There have been many attempts to form a satisfactory conceptual framework for the construction of a rational theory of turbulent flow. Well over half a century ago Reynolds considered a turbulent flow as consisting of a mean flow on which were superposed fluctuations. He showed that the effect was to introduce six additional stress components in the equations of motion, the components of a turbulent stress tensor. The shear stresses arose from a correlation between the components of the fluctuations. However, no method is known of computing the magnitude of the fluctuations and of the correlations between the several components.

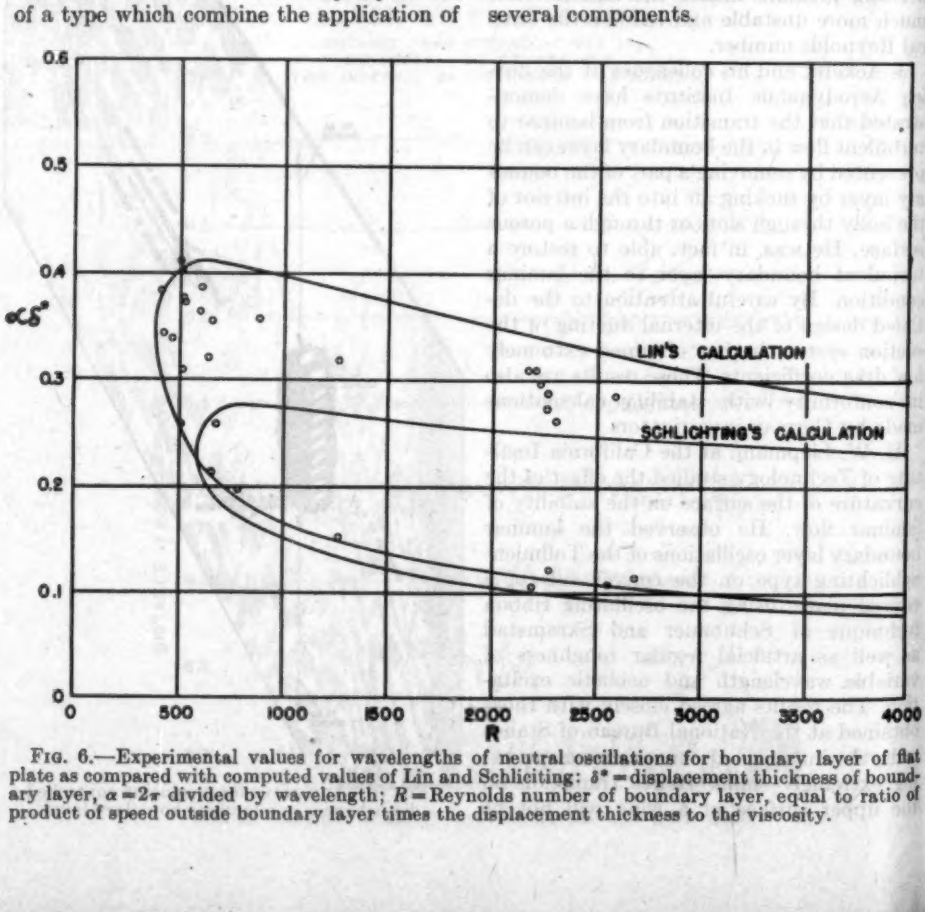

FIG. 6.—Experimental values for wavelengths of neutral oscillations for boundary layer of flat plate as compared with computed values of Lin and Schliciting: δ^* = displacement thickness of boundary layer, $\alpha = 2\pi$ divided by wavelength; R = Reynolds number of boundary layer, equal to ratio of product of speed outside boundary layer times the displacement thickness to the viscosity.

The general analogy between the turbulent fluctuations and the motions of the molecules of the fluid was noticed long ago, and attempts made to consider the effect of turbulent fluctuations as increasing the viscosity, increasing the rate of diffusion, and as transferring momentum or vorticity from one layer to another by processes similar to those considered in the kinetic theory of gases. Prandtl introduced the concept of mixing length as somewhat analogous to the mean free path in kinetic theory. The general theory was developed in terms of the mixing length but some empirical assumption had to be made about the mixing length itself. Prandtl assumed that it was related to geometrical parameters such as distance from the wall and boundary layer thickness. Von Kármán assumed in his similarity theory that the mixing length depended on the velocity gradient and higher space derivatives of the velocity. A characteristic assumption underlying all of these theories is that the velocity fluctuations at a point can be expressed quantitatively in terms of the mean flow in the neighborhood of that point. A disturbing feature is that the mixing length is a considerable fraction (about 0.4) of the thickness of the boundary layer but since an undetermined multiplication factor is always present, misgivings on this point have been ignored.

G. I. Taylor showed how the notion of mixing length could be defined in precise terms for a continuum and developed the foundations of a statistical theory of turbulence.

So long as the experimental material available for comparison with theoretical results was confined to measurements of mean speed distribution, boundary layer thickness, skin friction, and similar quantities, little progress could be made. Widely different mixing length distributions give nearly indistinguishable speed distributions. The hot-wire anemometer has made possible measurements of the fluctuations themselves, of correlations, and of the turbulent stress tensor. Some data have recently become available from experiments by my colleagues Schubauer, Klebanoff, and Squire at the National Bureau of Standards. The results at hand were presented in a paper at the Sixth International Congress for Applied Mechanics in Paris last September, which will soon be published. This is not the occasion to describe the methods or details of the results. I wish, however, to summarize the interpretation placed on the results at the present moment.

Fig. 7 shows the coefficient of shearing stress plotted against the mean velocity gradient for traverses of the boundary layer at three stations. Over extended regions of the boundary layer the velocity gradient changes very little, yet the shearing stress changes by a factor of 4 or 5. These curves do not suggest any very basic relation between the turbulent shearing stress and the mean velocity gradient.

From the measurements of the components of the turbulent stress tensor it is possible to compute the direction of the principal axis of the stress tensor and to compare this direction with the direction of the deformation tensor. The results are shown in Fig. 8. The direction of principal dilata-

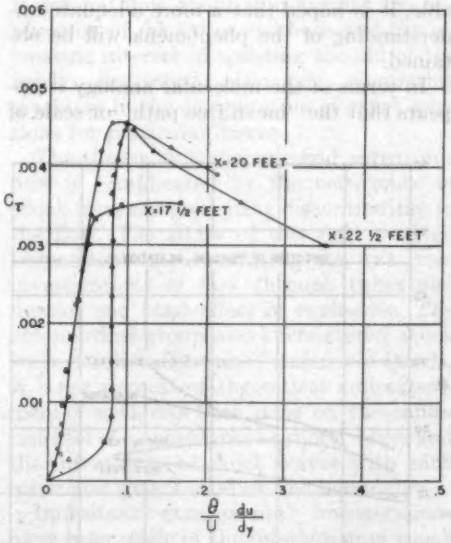

FIG. 7.—Turbulent shear stress coefficient in turbulent boundary layer as function of gradient of mean speed: C_τ = turbulent shear stress divided by velocity pressure; u = local mean speed; y = distance normal to surface; U = mean speed outside boundary layer; θ = momentum thickness of boundary layer.

tion in the approximately parallel shear flow of the boundary layer is at 45° to the flow direction. The direction of the principal axis of the stress tensor is from 10° to 30°. Expressed in more familiar language, there are directions at any point for which there is a shear stress but no rate of shear of the mean flow, and other directions for which there is no shear stress although there is a finite rate of shear of the mean flow. These results can not be explained in terms of a single scalar mixing length and suggest that the turbulent stresses at a point are not simply related to the mean flow in the neighborhood of the point. The stresses probably depend on the diffusion of turbulence from a considerable distance.

Other types of measurements are in progress. For example correlation measurements between fluctuations at points some distance apart in the same cross section of the boundary layer show that the correlation differs from zero over distances comparable with a large fraction of the boundary layer thickness. As further experimental measurements on the fluctuations become available, it is hoped that a more adequate understanding of the phenomena will be obtained.

In terms of the molecular analogy it appears that the "mean free path" or scale of the turbulent processes is large compared with dimensions in which we are interested. We must think in terms of considerable masses of fluid moving more or less coherently. The process can not be smoothed by averaging over a small volume because we can not choose dimensions small compared with those in which we are interested and at the same time large compared to a single fluid element. We are therefore asking ourselves questions of the following types: (1) Shall we regard the flow as a mean flow which merely transports and distorts large eddies superposed on the flow, these eddies being of varying size and intensity? or (2) Shall we regard the flow as a nonstationary flow made up of traveling wave systems, each wave extending across the entire boundary layer and traveling at a speed determined by the geometry of the whole boundary layer, the speed outside the boundary layer, and the physical properties of the fluid? The search is still for that method of approach that will be most useful in understanding the flow.

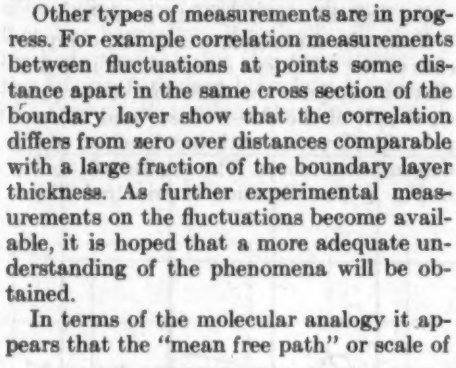

FIG. 8.—Angle between axis of turbulent stress tensor and the direction of mean flow: α = angle in degrees; y = distance normal to the surface; δ = thickness of boundary layer.

Another of the typical situations in complex flow patterns which has received considerable study is that in which the boundary layer separates from the surface, i.e., the direction of flow very near the surface reverses. The separation of a laminar boundary layer is fairly well understood; it arises in the presence of an adverse pressure gradient in the flow outside the boundary layer. After separation the boundary layer persists as a free boundary layer, i.e., region of steep velocity gradient. Transition eventually occurs in the free layer and under suitable conditions the layer may reattach itself to the body as a turbulent boundary layer.

Separation of a turbulent boundary layer also occurs in the presence of an adverse pressure gradient. We are engaged in a study of this phenomenon at the National Bureau of Standards. The results to date show that as separation is approached the turbulent shear stress near the wall falls regularly and smoothly as separation is approached. The falling stress is due to decreased correlation between the components of the velocity fluctuations and not to a decrease in their magnitude.

Perhaps the most obvious development in aerodynamics in recent years is the emergence of widespread interest in high-speed aerodynamics associated with the development of high-speed aircraft, jet propulsion, rockets, and large missiles. High speeds are measured in terms of the Mach number, the name given to the ratio of the speed of the aircraft or missile to the speed of sound. Aircraft are now beginning to operate in the transsonic range, i.e., at Mach numbers between 0.8 and 1.2, in which region the local relative air velocity reaches and exceeds the speed of sound (1127 ft/sec or 767 miles per hour at a temperature of 20°C). Speeds corresponding to Mach numbers greater than 1.2 are termed supersonic speeds.

Supersonic speeds are not new. The 1919 model 16-inch gun fired a projectile weighing 2,340 pounds at an initial speed of 2,700 ft/sec corresponding to a Mach number of 2.4. Until very recently, however, these problems were in the domain of a separate science—ballistics. Now ballistics and aerodynamics are fusing into a single science as aircraft travel faster and missiles sprout wings. In addition to this mating of interests new vitality has been introduced into high-speed aerodynamics by the many physicists and mathematicians who have been brought into contact with its problems during the war. One of the physicists remarked to me that he had been surprised to find that all the problems in fluid mechanics had not been solved in the 1880's as he had supposed; in fact, the subject had proved to be so interesting and the problems so challenging that he had decided to remain in the new field.

The increasing number of mathematicians and physicists working in the field has led to steady progress in developing the fundamental mathematical theory of the transsonic and supersonic flow of a nonviscous compressible fluid, the foundations for which were laid by P. Molenbrock and S. A. Chaplygin nearly 50 years ago. Some of the landmarks in the development before the war were the Prandtl-Glauert linearized equations for subsonic two-dimensional flow, the Kármán-Tsien relation between incompressible and compressible subsonic flows, the Prandtl-Busemann graphical methods for solving problems in supersonic flow, and Ackeret's linearized treatment and Busemann's second order theory of supersonic flows. There were of course many other contributions familiar to workers in the field.

During the war much attention was given to the theory of subsonic and transsonic flow of compressible fluids and somewhat less attention until recently to supersonic flow. In this country the work was sponsored by the National Advisory Committee for Aeronautics; the Bureau of Ordnance, Navy Department; the Ordnance Department of the Army; the Bureau of Aeronautics, Navy Department; the Army Air Forces; and the Office of Scientific Research and Development. Much of the theoretical work is in process of declassification and should soon be generally available.

Here it must suffice to mention only a few items as illustrative of the character of the work, i.e., the development of the theory of supersonic conical flows and their application to a linearized theory of the three dimensional flow about thin airfoils, the application of relaxation methods and the increasing interest in enlisting the aid of the newly developed electronic computing machines in the computation of exact solutions for particular cases.

The theory of transsonic and supersonic flow is complicated by the occurrence of shock waves, representing discontinuities in the flow. The study of this field received tremendous impetus during the war from investigations of flow through tubes and nozzles and blast effect of explosives. The aeronautical group also encountered shock waves as aircraft attained transsonic speeds. A large amount of theoretical and experimental work has been done on the conditions for the appearance of shock waves and the interaction of shock waves with each other and with a solid or free boundary.

Important experimental investigations have been made of the interaction of shock waves and boundary layers on wing sections by J. Ackeret at the Zurich Aeronautical Institute and by H. W. Liepmann at the California Institute of Technology. The shock-wave pattern depends markedly

on whether the flow in the boundary layer is laminar or turbulent and the shock wave does not always cause the flow to separate from the surface, although a characteristic feature of high speed flow as described for example by John Stack of the NACA in the Eighth Wright Brothers Lecture of the Institute of the Aeronautical Sciences is the early separation of the flow from the surface of the airfoil and the accompanying prominent shock wave. The interpretation of these results is that the effects of Reynolds number, i.e., scale, are not independent of the effects of Mach number and vice versa. Knowledge of the state of flow in the boundary layer is essential to the correct interpretation of model experiments at high Mach numbers.

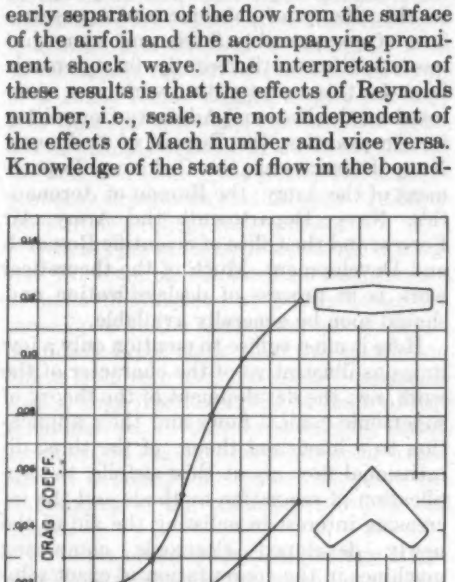

FIG. 9.—Effect of sweep on drag at high speeds: Mach Number = ratio of speed to speed of sound.

The investigators who were sent into Germany at the end of the war to study the accomplishments of German research found many models and a few full-scale aircraft with sharply swept-back wings. The research laboratories had produced many reports on the Pfeilflügel or arrow-wing. This plan form was first suggested for supersonic flight by A. Busemann at a scientific congress in Rome in 1935. At that time, however, no one was seriously interested in achieving supersonic flight, and the idea received little attention. Some time during the war A. Betz, of Göttingen, saw that the use of this plan form would increase the critical Mach number at transsonic speeds, i.e., the Mach number at which the drag increased very rapidly because of compressibility effects. He patented the idea and with other German scientists promoted its application to high speed aircraft. Fig. 9 illustrates the general nature of the benefit to be obtained.

R. T. Jones, of the NACA Langley Laboratory, independently realized the advantages of sweepback, developed a theory, and had made some tests before the German information was available in this country. The theory shows that the flow around a wing of constant section moving through a still fluid is determined solely by the normal component of the velocity of the solid boundaries. Hence if the wing is swept back so that the component of the velocity normal to the span is less than the critical speed for the wing section the flow will have the characteristics of subsonic flow. These advantages of sweepback are offset by some disadvantages which require further study, but this development is considered to constitute an important advance.

Such are some of the recent advances in aerodynamics in its more fundamental and basic phases. Apologies are made to any scientist in the field who may find his accomplishments overlooked in this brief sketch. It is hoped that the declassification of fundamental scientific work and the freer exchange of such information with our fellow workers abroad may permit a more adequate review at some later date.

I have tried to bring to you a little of the fascination of scientific research carried out for the purpose of comprehending physical phenomena and to outline some of the problems in the field of aerodynamics. I think that research carried out in this spirit in all fields of science is essential to progress.

ARCHEOLOGY.—*Note on some potsherds from northeastern Wyoming.*[1] WALDO R. WEDEL, U. S. National Museum.

The handful of pottery fragments on which the following remarks are largely based was collected by George Howes, of Beulah, Wyo., and came to the writer's attention through Dr. F. H. H. Roberts, Jr., of the Bureau of American Ethnology. They are said to have been found by Mr. Howes while he was plowing at his farm on Sundance Creek about 10 miles east of the town of Sundance, in Crook County. The locality is approximately 25 miles east southeast of Devils Tower National Monument and 10 or 12 miles from the South Dakota boundary. Sundance Creek flows northeast across the flank of the Black Hills uplift to drain eventually into the Belle Fourche River just below Belle Fourche, S. Dak.

Twenty-six sherds comprise the sample. In size, none exceeds 1¼ inches (32 mm) in greatest dimension, and about half are under 20 mm in diameter. This fact imposes obvious limitations on any inferences that may be drawn, but inasmuch as the type of ware seems not to have been illustrated and described in any detail heretofore it is believed the present series is worthy of record.

When received the sherds were coated with a very tenacious fine red dirt. Their color as revealed after washing was a very dark gray to nearly black, with inner surfaces generally lighter in tone. One bears a thin light reddish exterior layer that resists washing and appears to be a true slip. The others are unslipped, but several have a polished or lustrous outer surface. Tempering consists of small angular bits of sand, used very sparingly. Tiny flecks of mica may be detected in the dark paste. Twenty-four of the sherds are between 3.5 and 5 mm thick, and none exceeds 7 mm.

Included in the series are five rimsherds (Fig. 1, *a–d*, *h*), each of which extends 17 to 28 mm below the lip of the original vessel. The lip in each case bears small diagonal incisions averaging 5 to 7 per inch. Incidental to their application the soft clay was pressed outward so that the lip slightly exceeds in width the thickness of the vessel wall immediately below. Other than this there is no indication of a thickening or reinforcing of the rim which may be regarded as intentional. Paralleling the lip on the exterior surface of three fragments (Fig. 1, *a–c*) are incised lines which may have encircled the vessel. The largest sherd has six of these. There are no lines or other decoration on the two remaining rim pieces other than the ticked lips.

Of the remaining (body) sherds nine bear incising in grouped parallel lines, but owing to the small size of the individual pieces the pattern of which they once formed a part is conjectural. Two of those illustrated (Fig. 1, *f*, *g*) show a series of apparently horizontal lines ending against others running obliquely; the latter may have been either paired diagonals or else the edge of a larger decorative area wherein the hachuring was at an angle to the horizontal. Adhering to the inner surface of the larger is a 1-mm layer of carbonized organic matter. The lines vary from deeply cut narrow incisions to broad round-bottomed grooves. On one small sherd there are shallow indistinct impressions alternating with ridges suggestive of the tooled or paddle-marked surface seen on much of the pottery produced in historic times by the Mandan and Pawnee (Holmes, 1903, pl. 175; Will and Spinden, 1906, pls. 37, 41; Wedel, 1938, pl. 6, *1*). Others have a slightly scratched or brushed appearance, though this may have been unintentionally produced. Six exhibit only plain smoothed exteriors.

Little regarding the associated artifact types and nothing as to the probable form of habitation is known. The ubiquitous "snubnose" or end scraper of the Plains is said to be present as are small projectile points with or without a single pair of lateral notches and leaf-shaped knives or spearheads.

To the best of my knowledge sherds definitely of the type just described have not yet been reported from Nebraska or South Dakota, the States nearest Wyoming

[1] Published by permission of the Secretary of the Smithsonian Institution. Received February 27, 1947.

where archeological fieldwork has to date given true time perspective. However, on leafing through one of my old notebooks containing incidental observations made during a hunting trip in Cherry County, northern Nebraska, I find the following entry under date of November 1, 1931:

"Drove to a very interesting site on the right (south) bank of Snake River, at the bridge leading to the forest reserve, about 2 or 3 miles above the falls. Removal of the sand by wind has exposed a rather firmer black surface, perhaps 3 acres or so in extent. Numerous sherds, all very badly broken up and small, are to be picked up—are characteristically dark gray with a red core, sand or grit tempered, with thin non-collared rims decorated by parallel incised lines which encircled the vessel, and nearly always with tiny diagonal incisions cut into the lip. . . . Arrowpoints are predominantly small and triangular, unnotched, of white or gray chert, etc. Broken animal bones are present, but few if any traces of hearths and none of lodge sites. Is about 50 yards from the Snake River, in a well sheltered location. There are said to be similar sites about 2 miles up Boardmans Creek, which joins the Snake some 2 miles above this site."

The locality referred to is in the central part of the county, approximately 25 miles southwest of Valentine and 8 miles south of Burge Post Office. About one-third of a small full-bodied pot with loop handles, decorated with alternate groups of parallel incised lines and triangular areas filled with minute punctate marks, is said to have been

FIG. 1.—Potsherds from Sundance Creek, northeastern Wyoming.

found on this site. If memory spurred by the above note is to be trusted, the sherds did not vary significantly from those from Sundance Creek.

The Sundance potsherds are reminiscent also of others I have seen from Brown County on the Niobrara, from Antelope and Madison Counties on the middle Elkhorn, and of some described to me but not actually seen from the vicinity of Callaway on the South Loup River. Perhaps the pottery described by Buker (1937, p. 80) from Edgemont, S. Dak., as having "vertical lines interrupted by diagonal sets of parallel lines" is also related. The Elkhorn Valley sherds occurred with small triangular unnotched arrowpoints, grooved mauls, quartzite anvil stones, and, I believe, disk pipe fragments. The decoration on all this pottery somewhat suggests certain protohistoric types in eastern Nebraska, especially Oneota and Lower Loup Focus (Pawnee) wares—or at any rate it approaches these more closely than it does anything yet described for the prehistoric period (Hill and Wedel, 1936, pls. 3–5; Dunlevy, 1936, pls. 4–6; Wedel, 1938, pls. 4, 5; cf. Will and Spinden, 1906, pl. 38). Vessel shapes are unknown, but from the thinness of the sherds generally it is likely the pots were mostly small. Affiliations seem eastern (Missouri Valley) rather than western; the time period indicated is probably late prehistoric or early protohistoric.

Until this particular ware is definitely allocated to a specific archeological complex, its relationships will remain nebulous. Nevertheless, the Pawnee can be safely ruled out as its bearers, since their pottery is on the whole readily distinguishable. It may be significant that the Elkhorn in early historic times was claimed by the Omaha, the Niobrara by the Ponca. Still farther west at various times were the Comanche, Kiowa, and finally the Dakota. Whether one or more of these, or perhaps some entirely different tribe, is to be credited with dispersion of the ware herein described is for the future to disclose.

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GEOLOGY.—*Geology of Hat Island, Great Salt Lake, Utah.*[1] ELIOT BLACKWELDER, Stanford University.

Although the islands in Great Salt Lake, Utah, were visited and surveyed by Captain Stansbury in 1849, little more is known about their geology today than the brief notes in his report.[2] In fact, none of the islands have ever been adequately studied by geologists. One of the most inaccessible of them is a low rocky island known as Hat Island or Bird Island.[3] It is situated in the central part of the lake about 4 miles north of Carrington Island and 12 miles southwest of Promontory Point. In connection with the Salt Lake meeting of the American Association for the Advancement of Science, the writer took advantage of the opportunity afforded by a zoological excursion to visit the island on June 16, 1933.

As seen from the east, the island looks

[1] Received February 10, 1947.

[2] STANSBURY, H. *Exploration and survey of the valley of the Great Salt Lake of Utah, etc.* U. S. 32d Congr. Spec. Sess., Sen. Ex. Doc. 3, 1853.

[3] Although Hat Island is the original name, the locality is more commonly called Bird Island by the people who live in the Salt Lake Basin. The latter name seems undesirable because not distinctive, in view of the fact that sea birds nest in abundance on several other islands in the lake. It is therefore to be hoped that the name given by Stansbury will be preserved.

like a low-crowned black hat resting upon the water. The rocky part is only a few acres in extent and rises about 50 feet above the water level of 1933, which was near zero on the government gauge at Black Point. The island is surrounded by a submerged platform averaging perhaps a thousand feet in breadth. This is thickly encrusted with uneven calcareous tufa, which is apparently being built at the present time. Slimy masses of algae impart to the rounded crusts, or bioherms, a mottled greenish-brown color and are believed to be the causal agents in the formation of the tufa. Spaces between the bioherms are filled with light gray oölitic sand similar in composition to the crusts.[4] At the 1933 stage of the lake the platform was covered with about 3 feet of water, but near the shore of the island was a moatlike depression about 6 feet deep and 100 to 200 feet wide, for which no satisfactory explanation has been suggested. In more normal years the water is 10 to 15 feet deeper. The circumstance reminds one of a coral reef enclosing a lagoon.

Trailing off to the southeast of the island is an embankment of sand and gravel, which was formed as a broad shoal when the lake level stood higher. It consists of wave-worn fragments of hard rock and tufa, mingled with the prevailing oölitic sand.

The rocky part of Hat Island is composed almost wholly of a tilloid conglomerate identical in character with that exposed in Little Mountain, west of Ogden.[5] As in that locality, the rock is typically a massive dark gray argillite, well sprinkled with pebbles and boulders, among which white and gray metaquartzites and pinkish gneiss predominate. The matrix has a rude but evident cleavage, which would warrant calling it a bouldery slate, but the boulders are undeformed. For reasons that have already been sufficiently set forth in the writer's earlier paper, the rock is regarded as probably glacial and is therefore here called *tillite*.

The massive and otherwise structureless tillite is interrupted by two or three beds, or lenses, of stratified graywacke and fine conglomerate 2 to 4 feet thick. These beds were almost certainly comprised of sand and gravel that were sorted and deposited by streams of water, seemingly similar to deposits commonly associated with till in Pleistocene moraines.

On Hat Island neither the bottom nor the top of the tillite is exposed, but the visible thickness is roughly estimated as about 200 feet. The banded or varved slates, which form a significant member of the sequence at the south end of Little Mountain, were not observed on Hat Island.

The beds of graywacke strike N. 20° W. and dip eastward about 30°, whereas in Little Mountain the dip is westward. These relations suggest that the tillite of Hat Island may be the same formation as that in Little Mountain but reappearing on the western side of a broad syncline.

Nothing on Hat Island indicates the age of the tillite, but its similarity to other occurrences in the Salt Lake district suggests that the formation is late pre-Cambrian or possibly Lower Cambrian in age.

[4] Similar deposits and bottom conditions have been well described by A. J. EARDLEY, as he found them on other parts of the Salt Lake shore. (*Sediments of Great Salt Lake, Utah*. Bull. Amer. Assoc. Petr. Geol. **22**: 1305–1411. 1938.)

[5] BLACKWELDER, ELIOT. *An ancient glacial formation in Utah*. Journ. Geol. **40**: 291. 1932.

ZOOLOGY.—Disoma franciscanum, *a new marine annelid from California*.[1] OLGA HARTMAN, University of Southern California. (Communicated by WALDO L. SCHMITT.)

Numerous collections of an unknown member of the Disomidae, dredged by the U. S. Fisheries steamer *Albatross* during 1912 and 1913, form the basis of this report. The family is a small one, known through only scattered references from widely spaced geographic regions. Occurrence of its representatives, even in large collections, is extremely rare. The family is known for only eight (or not over ten) species. The genera, *Disoma* Oersted and *Poecilochaetus* Claparède, are usually the only ones recog-

[1] Received February 18, 1947. The illustrations for this paper were made by Anker Petersen.

nized, but the status of some other names remains enigmatical.

The family name, Disomidae, was erected by Mesnil (1897). It includes Disomididae Chamberlin (1919, p. 370) and Disominae Söderström (1920, p. 271). *Disoma* Oersted (1844) is the oldest genus; it was later named *Trochochaetus* Levinsen (1882) based on a posterior fragment of what later proved to be the genotype of *Disoma*. A later addition, *Nevaya whiteavesi* McIntosh (1911, p. 149) was first placed among the Scalibregmidae, but later shown to be another species of *Disoma* (Fauvel, 1916, p. 3). *Disomides* Chamberlin (1919, p. 370) was proposed to replace *Disoma* Oersted, since the latter was thought to be preoccupied; the family name was thus changed to Disomididae Chamberlin. This change was not required.

Another name, *Thaumastoma* Webster and Benedict (1884), was also referred to *Disoma* by Mesnil (1897, p. 94), but to me this view seems in error. The original and only known description is either incorrect on characters that have major importance or else the individual on which the genus was based departs so widely from all known members of the family that it is hardly inclusive in this group. It was erected for a single species, *T. singulare* Webster and Benedict (1884, pp. 737–739), from Massachusetts. A single injured specimen measured 16 mm long for 22 segments (hence only an anterior fragment). Identity with *Disoma multisetosum* (Oersted) has been suggested (Mesnil, 1897), but this view may have been prompted by the presence of serrated parapodial lobes.

The following characters, based on the description, are at variance with those of *Disoma:* (1) Ventral setae of the first two segments were stated to be in two series, the one capillary, the other stout spines. In species of *Disoma* only the second neuropodium may have spines in addition to setae. (2) The first segment was said to have a median cirrus. (3) The second segment has notopodia provided with a fan of capillary setae, while in front is a thin projecting plate divided into six unequal lobes. When a serrated membrane is present, it is typically postsetal, not presetal, in position. (4) Behind the second segment all setae are capillary; no mention is made of modified acicular spines. (5) In the third segment a digitate plate is said to extend down the side of the body, presetal in position. If the author confused presetal with postsetal positions, in the instances mentioned above, the relations to *Disoma* are clearer, but there are other discrepancies that are not to be explained. Since the only known specimen on which the description was based is not known to exist, it seems advisible to regard *Thaumastoma singulare* as an indeterminable genus and species.

The only other genus of the family, *Poecilochaetus* Claparède (1875) was erected for an aberrant larva for which the sedentary stages were later found. Levinsen (1882, p. 104) recognized the affinities of *Disoma* and *Poecilochaetus*, based on a study of the larval stages of their respective species, but it was not until later that the family Disomidae was recognized and its members separated from those of the family Spionidae (Mesnil, 1897).

The generic name *Poecilochaetus*, like that of *Disoma*, is also obscured by systematic complexities. Much earlier, *Cherusca nitens* Müller (1858, p. 217) from Brazil, was described. Both the genus and species remain enigmatical and unknown except through a brief, original record. However, two characters ally it to *Poecilochaetus;* they are (1) the structure of parapodia, in having foliaceous dorsal and ventral lobes, and (2) the prostomial caruncle which has a branched, median antenna. In other respects the account of *Cherusca* is very sketchy and obscure.

The conclusions regarding the family Disomidae may be summarized as follows: Two genera, *Disoma* and *Poecilochaetus* are recognized. The first includes *Trochochaetus* Levinsen, *Nevaya* McIntosh, and *Disomides* Chamberlin; the second includes questionably *Cherusca* Müller; *Thaumastoma* Webster and Benedict is indeterminable.

Poecilochaetus Claparède is known from the Americas through a single species, *P. johnsoni* Hartman (1939, p. 164) from California. *Disoma* Oersted is known from the Western Hemisphere through two species, both from deep water off eastern Canada;

D. carica Birula, recorded as *Nevaya whiteavesi* McIntosh (see Fauvel, 1932, p. 24), and *D. watsoni* Fauvel (1932, p. 28). A third species, *D. franciscanum*, is described below.

The known species of *Disoma* may be approximately divided into two groups. In one the anterior, postsetal lobes are serrated. To this group belong the genotype, *D. multisetosum* Oersted (1844) known from northwestern Europe, and *D. franciscanum*. In the second group the postsetal lobes are entire. To it belong *D. carica* Birula from northern Europe and eastern Canada, *D. orissae* Fauvel (1932, p. 174) from India, and *D. watsoni* Fauvel (1916, p. 3). The last three named are not clearly distinguishable from one another (Fauvel, 1932, p. 174), since the last two are known through only short, imperfect, anterior fragments.

KEY TO SPECIES OF DISOMA OERSTED

1. Postsetal lobes entire..... .....*carica* Birula, *orissae* Fauvel, and *watsoni* Fauvel
   Postsetal lobes serrated in anterior segments.2
2. Third parapodium with a long cirrus..... .....*multisetosum* Oersted
   Third parapodium without a long cirrus..... .....*franciscanum*, n. sp.

Disoma franciscanum, n. sp.

Figs. 1–3

Collections.—San Francisco Bay, Calif., dredged by the *Albatross* during 1912 and 1913, from the following dredging stations (consult dredging and hydrographic records of the *Albatross*, 1911–1920: Appendix 3 to Rep. U.S. Comm. Fish. for 1920, Bur. Fish. Doc. No. 897, Washington, 1911, for more complete data). D5705 (2) D5706 (2), D5723 (1), D5729 (2), D5744 (1), D5754 (1), D5772 (1), D5828 (1), D5830 (18), D5831 (2), D5838 (many, with tubes). Depths range from 1 to 16 fathoms, bottom of mud and sand to shale.

Description.—Among the numerous individuals listed above, none is complete, but one may estimate the total, probable length from larger fragments. A longer piece, including anterior and median portions measures 60 mm long for 73 segments. Another piece, consisting of only posterior, biramous parapodia measures nearly as long. The total length (preserved) may thus approximate 150 to 200 mm. One of the collections (D5838) contains many tube fragments, some with individuals. Most tubes are flaccid and depressed to cylindrical in cross section; some of the larger ones are about 100 mm long and 6 mm wide. Since the tubes are fragile and easily broken, the total length is probably considerably more than 10 cm.

The body is depressed to cylindrical in cross section. An anterior region of 20 to 25 segments is more or less sharply set off from segments farther back; its rings are both shorter and wider, and its parapodia more fully developed than those farther back. Most individuals have lost the long, paired palpi but some retain longer or shorter portions of these structures, in their normal attachment, at the sides of the prostomial caruncle (Fig. 1, *a*).

The body consists of three regions, (1) an anterior one of about 20 to 25 segments in which parapodia are biramous (except the second segment which is uniramous), (2) a median region of 70 or more segments in which parapodia are uniramous, and (3) a posterior region of 90 or fewer segments in which they are again biramous. The change from anterior to median regions, is transitional in that notopodia come to be gradually smaller and disappear as small papillae. The change from median to posterior regions is also gradual; notopodia again appear gradually, although they never come to be as large. The total number of segments may thus be 150 to 200, consisting of 20 to 25 anterior, 70 or more median, and 90 or fewer posterior, ones. An accurate count is not possible because it is difficult to estimate exact levels where specimens are broken.

The presence of a third body region for species of *Disoma* was first recorded by Levinsen (1882, p. 129), for which he erected *Trochochaeta sarsi;* Michaelsen (1897, p. 41) showed it to be the posterior end of *Disoma multisetosum* Oersted.

The prostomium is an elongate, flat ridge, narrowed and rounded at its anterior margin when the proboscis is retracted, or somewhat weakly trilobed when the proboscis is everted. It widens just in front of the palpal attachentm but narrows again farther back and is continued behind the palpal bases as a narrow caruncle, such as characterizes species of *Poecilochaetus* Claparède. Normally the prostomium is directed downward at its anterior end; thus it is seen with difficulty in dorsal view, and fully

only in frontal view. There are three or four inconspicuous eye spots at the sides of the prostomium, between the palpal bases. They are small in size, more or less deeply embedded and easily overlooked.

The palpi are probably long in life and capable of great extension. Preserved, they are greatly shrunken and fallen from most individuals. As in members of the family Spionidae, they are nearly cylindrical processes and have a deep, longitudinal groove along one side, facing the mouth; they have dark pigment

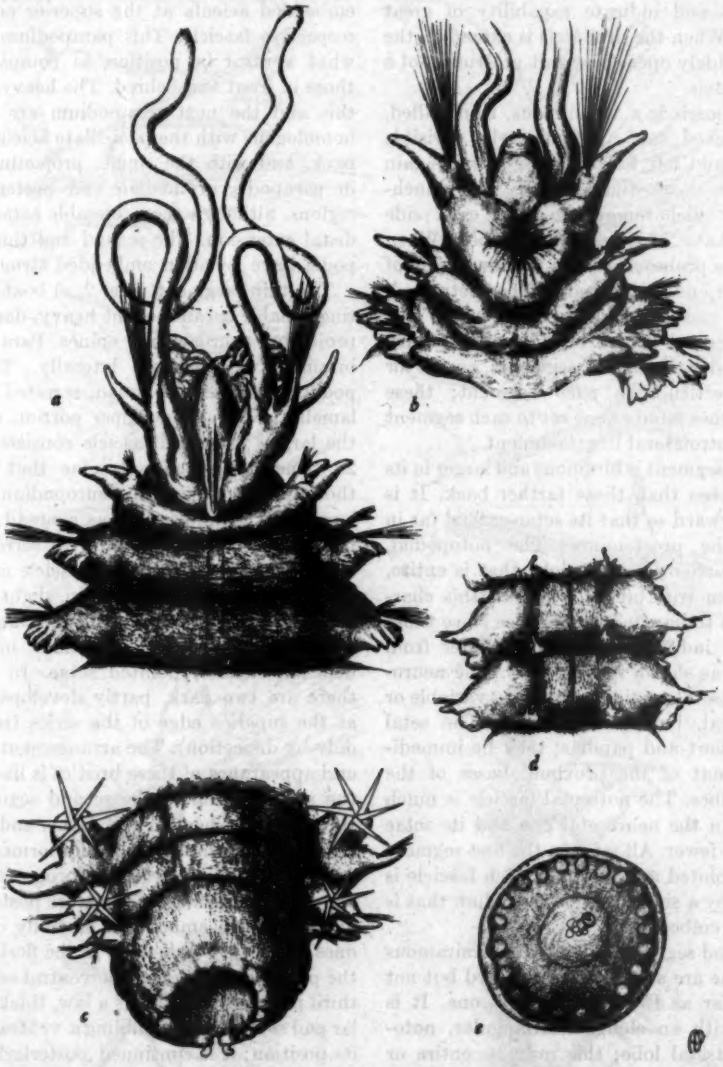

FIG. 1.—*Disoma franciscanum*, n. sp.: *a*, Anterior end including first four segments, with proboscis partly everted, in dorsal view, ×50; *b*, anterior end including first three segments, distal ends of palpi not shown, in ventral view, ×50; *c*, posterior end including pygidium and last three segments, in dorsal view, ×110; *d*, two segments from posterior region of body, in ventral view, ×46; *e*, ovum from body cavity, seen in optical section through the long axis, ×600.

along the sides of the groove. When fallen away, they leave a long, oval scar of attachment at the sides of the prostomial ridge.

The mouth is a large, triangular area on the ventral side of the first segment. When the proboscis is retracted, the anterior and posterior edges of the mouth are strongly ridged (Fig. 1, *b*) and indicate capability of great extension. When the proboscis is extended, the mouth is widely open to permit protrusion of a large proboscis.

The proboscis is a voluminous, thin-walled, much-branched sac, approximately divisible into right and left halves; each half is again divided into short, digitate lobes, the branching largely dichotomous so that each side comes to have 16 to 20 short lobes. When everted, the proboscis covers the lower side of the anterior end of the body. When retracted, it occupies most of the body space in the first four segments. Thereafter, the alimentary tract is slender through 17 segments, except for paired diverticula in each segment; these paired pouches number one set to each segment and are ventrolateral in attachment.

The first segment is biramous and larger in its postsetal lobes than those farther back. It is directed forward so that its setae extend far in front of the prostomium. The notopodial, postsetal portion is a long lobe that is entire, bifid or even trifid at its free end (this character seems to have no significance since those of a single individual frequently differ from each other as shown in Fig. 1, *a*). The neuropodial, postsetal portion is similarly variable or asymmetrical, but usually entire. The setal lobes are short and papillar; they lie immediately in front of the proximal bases of the postsetal lobes. The notosetal fascicle is much smaller than the neurosetal one and its setae shorter and fewer. All setae in the first segment are long, pointed and straight; each fascicle is supported by a single, slender aciculum that is completely embedded.

The second segment (Fig. 2, *b*) is uniramous and its setae are also directed forward but not nearly so far as those of the first one. It is provided with an elongate, triangular, notopodial, postsetal lobe; this may be entire or slightly serrated to form two or three shorter lobes. There is considerable irregularity and asymmetry in this respect, just as for the postsetal lobes of the first segment. There is no notopodial fascicle or papilla (or even notoaciculum). The setigerous lobe is an elongated ridge and provided with four or five projecting, dark-yellow spines (actually the emergent acicula), alternating with, but in front of, five slender, longer, pointed setae. In addition, there are two or three partly developed, dusky embedded acicula at the superior edge of its respective fascicle. This parapodium is somewhat ventral in position as compared with those in front and behind. The heavy spines of this and the next parapodium are probably homologous with the penicillate acicula farther back, and with the single, projecting acicula in parapodia of median and posterior body regions, although they resemble setae in their distal extension. The second and third neuropodia have no other embedded structure.

The third segment (Fig. 2, *c*) is at once distinguishable because of the heavy, dark brown, projecting neuroacicular spines. Parapodia are biramous and project laterally. The notopodium consists of a broad, serrated postsetal lamella in which the upper portion is usually the largest; its setal fascicle consists of 20 to 25 slender, pointed notosetae that resemble those farther back. The neuropodium is much larger and glandular; it has a broad postsetal membrane that is crenulate to serrate at its distal edge. The neurosetal fascicle consists of four or five heavy, dark brown, slightly curved acicula (spines) in a vertical series, anterior to, and alternating with, a similar number of delicate, slender, pointed setae. In addition, there are two dark, partly developed acicula at the superior edge of the series (to be seen only by dissection). The arrangement and general appearance of these bristles is like that for the neuropodium of the second segment, but the acicula are heavier and darker and the setae slenderer and smaller. The inferiormost acicula are anterior to those going progressively upward; the uppermost is therefore posteriormost and the small, embedded, partially developed ones are deeply embedded in the fleshy part of the parapodium. Below the ventral edge of the third parapodium there is a low, thick, glandular pad somewhat resembling a ventral cirrus in its position; it is continued posteriorly on segments 4, 7, 8, and farther back as a diminishing papilla. There is no long cirrus on the third segment, such as is present in *Disoma multisetosum* Oersted.

The fourth segment (Fig. 2, *d*) is characterized for its greatly expanded, serrated, postsetal lobes in both notopodia and neuropodia; they are largest and longest above. The notopodial one has about 13 short distal serrations (or several accessory ones); the neuropodial one has about eight similar, or slightly smaller serrations of which the inferiormost are slightly the larger. The notopodium is armed with 16 to 18 slender, pointed setae supported by a single, slender embedded aciculum. The neuropodium has about 16 similar setae and a single aciculum. The setae resemble those farther back.

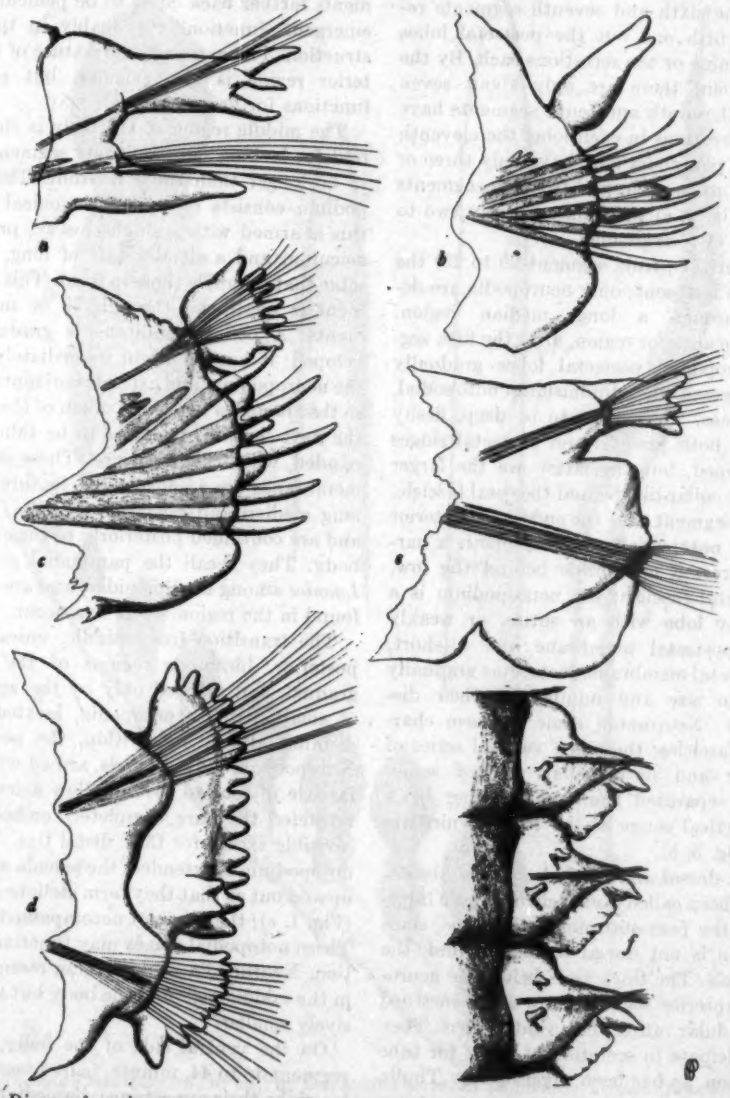

FIG. 2.—*Disoma franciscanum*, n. sp.: *a*, First parapodium in anterior view, ×88; *b*, second parapodium in anterior view, ×112; *c*, third parapodium in anterior view, ×112; *d*, fourth parapodium in anterior view, ×125; *e*, seventeenth parapodium in anterior view, ×112; *f*, right half of three far posterior segments in dorsal view, ×56.

The fifth segment resembles the fourth one but tends to have fewer serrations in its postsetal lobes. There are about nine in the notopodium (or up to six additional, weakly developed ones at the inferior end). Notopodial and neuropodial postsetal lobes are less unequal to each other than those in the fourth segment. The sixth and seventh segments resemble the fifth one but the postsetal lobes have about nine or ten serrations each. By the eighth segment there are only about seven serrations; the ninth and tenth segments have about six serrations in each lobe, the eleventh and twelfth parapodia may have only three or four serrations in each, and between segments 13 to 20 (Fig. 2, *e*) there may be only two to three lobes, or a single one.

Thereafter (i.e., from segment 20 to 25) the notopodium is absent; only neuropodia are developed through a long, median region. Through the anterior region, after the fifth segment, neuropodial postsetal lobes gradually come to exceed the diminishing notopodial, postsetal ones. They come to be deep, fleshy lobes, with both presetal and postsetal ridges well developed, but the latter are the larger and project collar-like behind the setal fascicle. Thus, at a segment near the end of the anterior region, the notopodial postsetal lobe is a narrow, compressed membrane behind the low, papillar, setal fascicle; the neuropodium is a deep, fleshy lobe with an entire, or weakly serrated, postsetal membrane and a short, entire, presetal membrane. Notosetae gradually diminish in size and number to their disappearance. Neurosetae come to form characteristic fascicles; there is a vertical series of preacicular and postacicular pointed setae; these are separated from one another by a similar vertical series of ten to 15 penicillate acicula (Fig. 3, *b*).

Distinct dorsal and ventral cirri are absent. What has been called dorsal cirrus is here interpreted as the postsetal, notopodial lobe, since its position is not dorsal to, but behind, the setal fascicle. The thick pads below the neuropodia in anterior segments are also construed to be glandular rather than ventral cirri. They may participate in secretion of fibers for tube construction, as has been suggested by Thulin (1921, p. 12).

Long, pointed simple setae are present in all notopodia and neuropodia, but those in the second neuropodium are greatly reduced. Acicula are present in all parapodia and some are modified for special uses. Those in the first segment are slender and embedded as are also those in notopodia farther back. Those in the second and third neuropodia are greatly developed and emergent; those in neuropodia of segments farther back come to be penicillate and emergent, functioning probably in tube-construction. The notopodial armature of the posterior region is also acicular, but probably functions for grasping.

The middle region of the body is characterized for lacking notopodia; its segments come to be longer than those in front. The neuropodium consists of a simple, conical papilla; this is armed with a single, heavy, projecting aciculum and a slender tuft of long, pointed setae that resemble those in front. This arrangement is continued through 70 or more segments. A podal membrane is gradually developed; it has its origin immediately behind the neuropodium and extends horizontally back so that it comes to occupy much of the space to the next septum. It comes to be thin and expanded, with frilled margins. These segmental membranes are a conspicuous feature through long median and posterior (Fig. 2, *f*) regions and are continued posteriorly to the end of the body. They recall the parapodial pouches of *Laonice* among the Spionidae, and are similarly found in the region where ova occur.

The transition from middle, uniramous, to posterior, biramous regions of the body is gradual, and marked only by the appearance of small, papillar notopodia, located a short distance above, and within, the neuropodia. Notopodia are low mounds, armed with a close fascicle of four to seven yellow acicula; when retracted they are completely embedded and invisible except for their distal tips. When the notopodium is extended, the acicula are pushed up and out so that they form stellate structures (Fig. 1, *c*); they are not accompanied by setae. These notopodial spines may function for traction. Neuropodia in this region resemble those in the middle region of the body but are successively smaller.

On the ventral side of the body, at about segment 40 to 44, minute, paired ventral papillae make their appearance, immediately within the line forming the proximal portion of the neuropodia. They gradually develop to form

slender, short filaments and come to be most conspicuous in the posterior region (Fig. 1, *d*) where they consist of one to three filaments on a side; they arise from a low mound. These structures were first described by Levinsen (1882) and called branchiae. Michaelsen (1897, p. 41) showed that they are retractile; he recorded their presence for *D. multisetosum* Oersted from about the twentieth segment. Eisig (1914, p. 536) concluded that, morphologically, they are not branchiae since they have their origin away from the notopodium,

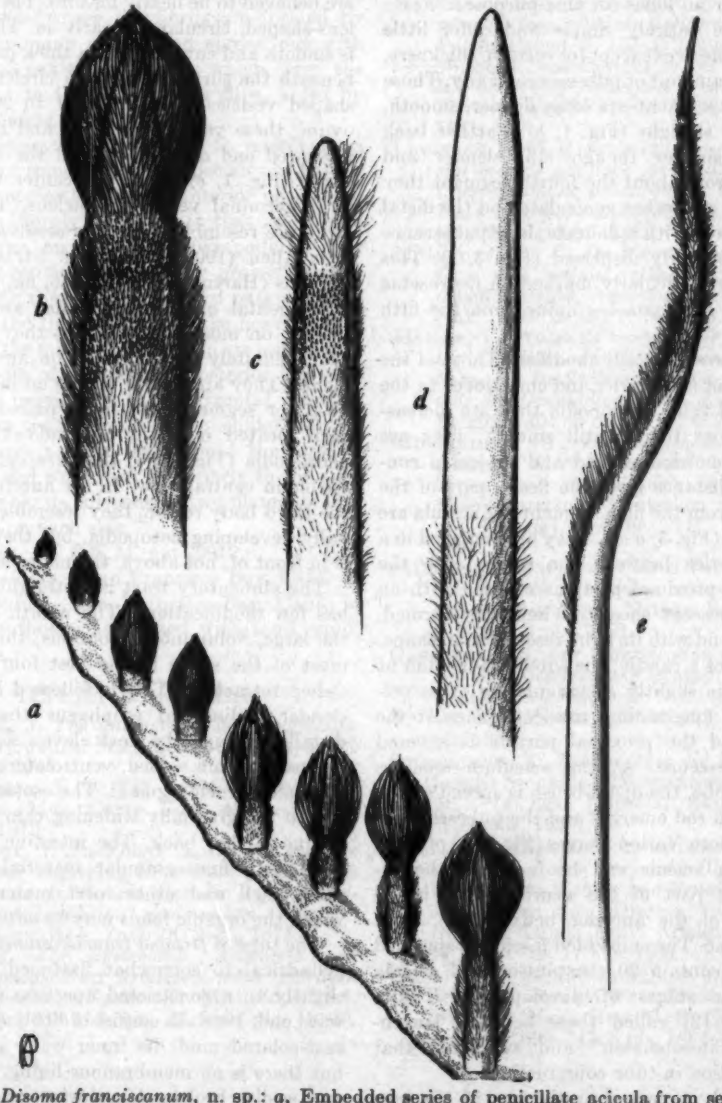

FIG. 3.—*Disoma franciscanum*, n. sp.: *a*, Embedded series of penicillate acicula from seventeenth thoracic neuropodium, showing successive stages in development, ×940; *b*, distal end of developed penicillate aciculum, ×1160; *c*, distal end of emerged penicillate aciculum, with brush partly worn away, ×780; *d*, worn penicillate aciculum from inferior part of fascicle, ×658; *e*, thoracic neuroseta showing fringe at distal end, ×940.

but that they more nearly resemble the lymph branchiae of some capitellids and glycerids. From their position and structure, however, it might be suggested that they function in sensory reception, since parapodia of their respective segments are unusually simple and have few or no lobes for this purpose.

Setae are entirely simple and differ little among themselves except for relative thickness, length and amount of pubescence, if any. Those in the first segment are long, slender, smooth, and nearly straight (Fig. 1, *b*). Farther back they are shorter though still slender and straight. From about the fourth segment they come to be somewhat geniculate and the distal end is covered with a delicate, long pubescence that is irregularly dispersed (Fig. 3, *e*). This hairiness is particularly marked on neurosetae in anterior segments beginning from the fifth one.

Acicula are variously modified. Those of the first segment are slender and embedded. In the second and third neuropodia they are increasingly heavier though still smooth; they are distally somewhat curved and project a considerable distance from the fleshy part of the podium. From the fifth segment the acicula are penicillate (Fig. 3, *a–d*). They are arranged in a vertical series between the setae, with the distal and proximal portions covered with an outer, pubescent sheath. When fully formed, the distal end with its hairs resembles, in shape, the flame of a candle; the subdistal portion of the shaft is slightly rectangular in cross section, with longitudinal rows of spines at the angles, and the proximal portion is covered with pubescence. As the aciculum emerges from the lobe, the distal brush is spread apart, the smooth rod emerges and the pubescence is gradually lost. Various stages (Fig. 3, *a*) of these developing acicula can be found in the superiormost part of the neuropodium, in all segments of the anterior body region, from the fifth one. The embedded fascicle is spiralled and may contain 20 chestnut-colored acicula in various stages of development. Thulin (1921, p. 12) called these acicula "lanzenformige Pinselborsten" and suggested that they function in tube construction.

The body tapers abruptly toward the posterior end and terminates in a thick, collar-like pygidium (Fig. 1, *c*) with a large, circular anal aperture; the ventral edge of the collar is incised and provided with a pair of subspherical, tiny processes which lie proximal to each other, in a transverse direction.

In some individuals ova are present in great number, in the hinder median and posterior segments of the body; in some instances they are believed to be nearly mature. They are flat, lens-shaped, circular or nearly so. The surface is smooth and covered with a thick membrane; beneath the surface there is a circlet of flask-shaped vesicles, numbering 21 to 29 in each ovum; these vesicles are clear and have their narrowed end directed toward the egg membrane (Fig. 1, *e*). Near the center there is a large germinal vesicle or nucleus. The entire structure resembles that of *Poecilochaetus serpens* Allen (1904, pl. 12, fig. 64) and some spionids (Hartman, 1941, pl. 46, fig. 19).

Segmental organs (nephridia) are perhaps present on most segments but they have not been definitely distinguished on anterior segments. They are clearly visible on median and posterior segments as small, paired papillae, each located near the anterodorsal edge of neuropodia (Fig. 2, *f*); they are only slightly visible in ventral view. In the anterior part of the third body region, they resemble the gradually developing notopodia, but their position is in front of, not above, the neuropodium.

The alimentary tract is a straight tube and has few modifications. The mouth leads into the large, voluminous proboscis; this occupies most of the space in the first four segments (when retracted). This is followed by a long, slender, cylindrical esophagus that extends distally through the next eleven segments; it has paired, thin walled, ventrolateral pouches, one pair to each segment. The esophagus gives rise to the gradually widening thin walled intestine farther back. The intestine is usually filled with fine, granular materials, perhaps sand, shell and other inert materials, from which the organic foods may be sifted.

The tube of *Disoma franciscanum* is long and cylindrical to somewhat flattened. It tapers slightly to a constricted aperture at the forward end. Its walls consist of finely compacted, rust-colored mud; its inner walls are smooth but there is no membranous lining. The tubes are easily broken lengthwise or crosswise. There is no indication of anastomosing which Thulin (1921, p. 11) described for *D. multisetosum* Oersted.

According to Thulin (loc. cit.) the tube materials are held together by longitudinally arranged fibrils that are secreted from spinning glands, probably located in an anterior portion of the body. This author suggests that the process may be likened to that in some species of *Panthalis* (family Polyodontidae) described by Watson, where the fibrils are formed by certain spinning glands and spread out with the aid of penicillate bristles which carry the fibrils out to the walls of the tube, aided by the movement of other setae.

D. franciscanum resembles *D. multisetosum* Oersted in some respects, especially in having serrated postsetal lobes in anterior parapodia. It differs sharply, however, in that there is no long cirrus on the third parapodium. The former is provided with heavy projecting acicula in both the second and third parapodia but those of the third are by far the heavier. Segments of the middle body region are uniramous. Neuropodia of middle and posterior body regions are provided with a horizontal, lamellar membrane that comes to be pouchlike. Ventral papillae are present from about the fortieth segment and continued posteriorly to the end; they number usually one or two filaments to a segment, on each side.

Holotype.—U.S.N.M. no. 20912.

Type locality.—San Francisco Bay, Calif.

Distribution.—San Francisco Bay, Calif., in 1 to 16 fathoms, associated with sand, mud, and shale.

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ZOOLOGY.—*A new harpacticoid copepod from Bornean crabs.*[1]

ARTHUR G. HUMES, University of Connecticut. (Communicated by WALDO L. SCHMITT.)

A new copepod species from the gill chambers of various marsh crabs was collected at Tarakan, Borneo. The copepods were stained lightly with acid fuchsin, cleared in cedarwood oil, and mounted in clarite, either whole or in segmental dissections to show the appendages. The mouth parts and body segments with their appendages were separated using sharply pointed minuten nadeln.

Identifications of the Bornean crabs were made by Dr. Fenner A. Chace, Jr., of the U. S. National Museum. Paratypes and other specimens of the Japanese species were lent for study by the same museum. Service with the U. S. Navy in Borneo afforded opportunity for the collection of the new material.

Family CANTHOCAMPTIDAE

Pholetiscus, n. gen.

Generic characters.—General body shape resembling that of *Cancrincola* Wilson. Female abdomen 3-segmented; male abdomen 4-segmented. Caudal rami moderately short, both bearing terminally a seta two-thirds as long as the body and a shorter seta about one-fourth the length of the other. No anal operculum. Anterior antennae of female with six or eight podomeres; those of the male highly modified for clasping with three to eight podomeres difficult to distinguish. Posterior antennae short, with two or three podomeres, the exopodite minute or apparently absent. Mouth parts in general plan similar to those of *Cancrincola*, but differing in details. Swimming legs all biramous, first pair modified for clasping; in female exopodites 1–4 with three podomeres, endopodites 1–4 with two podomeres; in male rami are similar except for the third endopodite which has three podomeres. Fifth legs in female lamellar, with two podomeres, the basal one indistinctly separated from the body segment and expanded on the inner side; the distal podomere bearing two setae. Fifth leg in male reduced to a low ridge bearing three or four setae. A single ovisac.

Genotype.—*Pholetiscus wilsoni* (Pearse) = *Cancrincola wilsoni* Pearse, 1930.

Remarks.—This new genus may be easily separated from the genus *Cancrincola* on the basis of the several distinctions mentioned below. It includes the new species, *Pholetiscus orientalis*, herein described, and the species originally described by Pearse (1930) as *Cancrincola wilsoni*.

Pholetiscus wilsoni (Pearse, 1930)

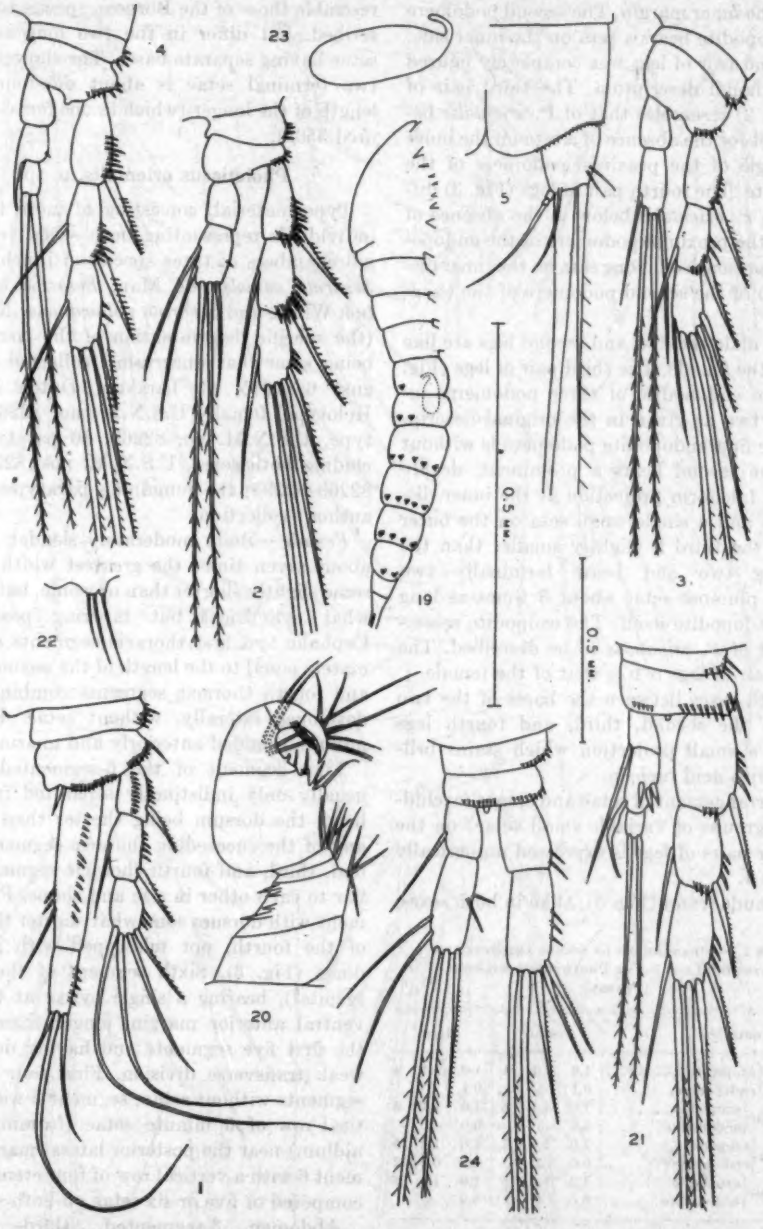
This species was first described from the gill chambers of two marsh crabs, *Sesarma haematocheir* (de Haan) and *Sesarma pictum* (de Haan), at Aburatsubo, Japan. An examination of Pearse's specimens, U.S.N.M. no. 62836, from *S. pictum*, apparently paratypic though not so labeled, shows several features not mentioned in the original description. The sixth thoracic segment (genital) has a weak transverse division dorsally, not seen on the ventral side. The female abdomen is 3-segmented, while that of the male is 4-segmented.

The anterior antennae of the male have more than three podomeres. The joints are difficult to interpret but the podomeres are similar to those of *P. orientalis* to be described below. Podomeres 3 and 4 are very poorly delimited, and are indicated only by slight differences in the thickness of the chitin to be seen in optical section. Podomere 5 is swollen at the outer proximal angle. Fifth and sixth podomeres bear rough protuberances on their inner margins. Seventh and eighth podomeres are indistinctly separated and curved back toward the fifth to form a prehensile organ. The anterior antennae of the female have six podomeres, the sixth perhaps representing the fusion of two or more podomeres. The relative lengths of the podomeres beginning basally are 9:8:5:5:3:7.

Whether the low protuberance at the base of each posterior antenna should be regarded as a distinct podomere is a matter for interpretation. Including this protuberance, the posterior antennae apparently have three podomeres.

The first four pairs of legs resemble in general those of *P. orientalis* described below. Since various setae were omitted in the original description, certain legs will be redescribed here. In the first leg of the female (Fig. 1) the proximal podomere of the endopodite bears a long, slender seta and two minute ones on the distal

[1] Received February 3, 1947.



FIGS. 1–5.—*Pholetiscus wilsoni* (Pearse): 1, First leg (female); 2, third leg (female); 3, fourth leg (female); 4, third leg (male); 5, caudal ramus (male).

FIGS. 19–24.—*Pholetiscus orientalis*, n. sp.: 19, Body segments (male); 20, anterior antenna (male); 21, third leg (male); 22, fifth leg (male); 23, spermatophore; 24, asymmetrical third leg (female).

All figures drawn with the aid of a camera lucida. The shorter of the two scales applies to Figs. 1–5; the longer only to Figs. 6 and 19.

third of the inner margin. The second podomere of the exopodite bears a seta on the inner side. The second pair of legs was completely figured in the original description. The third pair of legs (Fig. 2) resembles that of *P. orientalis* below except for the absence of a seta on the inner distal angle of the proximal podomere of the endopodite. The fourth pair of legs (Fig. 3) differs from *P. orientalis* below in the absence of setae on the proximal podomere of the endopodite and presence of a long seta on the inner distal region of the second podomere of the exopodite.

In the male the first and second legs are like those of the female. The third pair of legs (Fig. 4) has an endopodite of three podomeres instead of two as given in the original description. The first endopodite podomere is without setae; the second bears a prominent, deeply staining, falciform projection at the inner distal angle and a single small seta on the outer margin; the third is slightly smaller than the preceding two and bears terminally two sparsely plumose setae about 3 times as long as the endopodite itself. The exopodite resembles that of *P. orientalis* to be described. The fourth pair of legs is like that of the female.

In both sexes between the bases of the two rami on the second, third, and fourth legs there is a small projection which stains brilliantly with acid fuchsin.

The arrangement of setae and spines (excluding the groups of variable small setae) on the first four pairs of legs is expressed numerically in Table 1.

The caudal rami (Fig. 5), alike in both sexes,

TABLE 1.—ARRANGEMENT OF SPINES AND SETAE ON SWIMMING LEGS 1–4 OF PHOLETISCUS WILSONI (PEARSE)

Swimming leg		Female			Male		
First pair	exopodite	1,0	1,1	4	1,0	1,1	4
	endopodite	0,1	3		0,1	3	
Second pair	exopodite	1,0	1,1	5	1,0	1,1	5
	endopodite	0,0	3		0,0	3	
Third pair	exopodite	1,0	1,1	5	1,0	1,1	5
	endopodite	0,0	5		0,0	0,1	2
Fourth pair	exopodite	1,0	1,1	5	1,0	1,1	5
	endopodite	0,0	4		0,0	4	

Numbers to the left of the comma refer to the number of large spines or setae on the outer edge, those to the right to the number on the inner edge. Single numbers refer to terminal armature. Minute spines or setae are not considered because of their relatively wide variation in number. Scheme adapted from that of Kiefer (1928).

resemble those of the Bornean species to be described, but differ in the two long terminal setae having separate bases. The shorter of the two terminal setae is about one-fourth the length of the longer (which in one female measured 350μ).

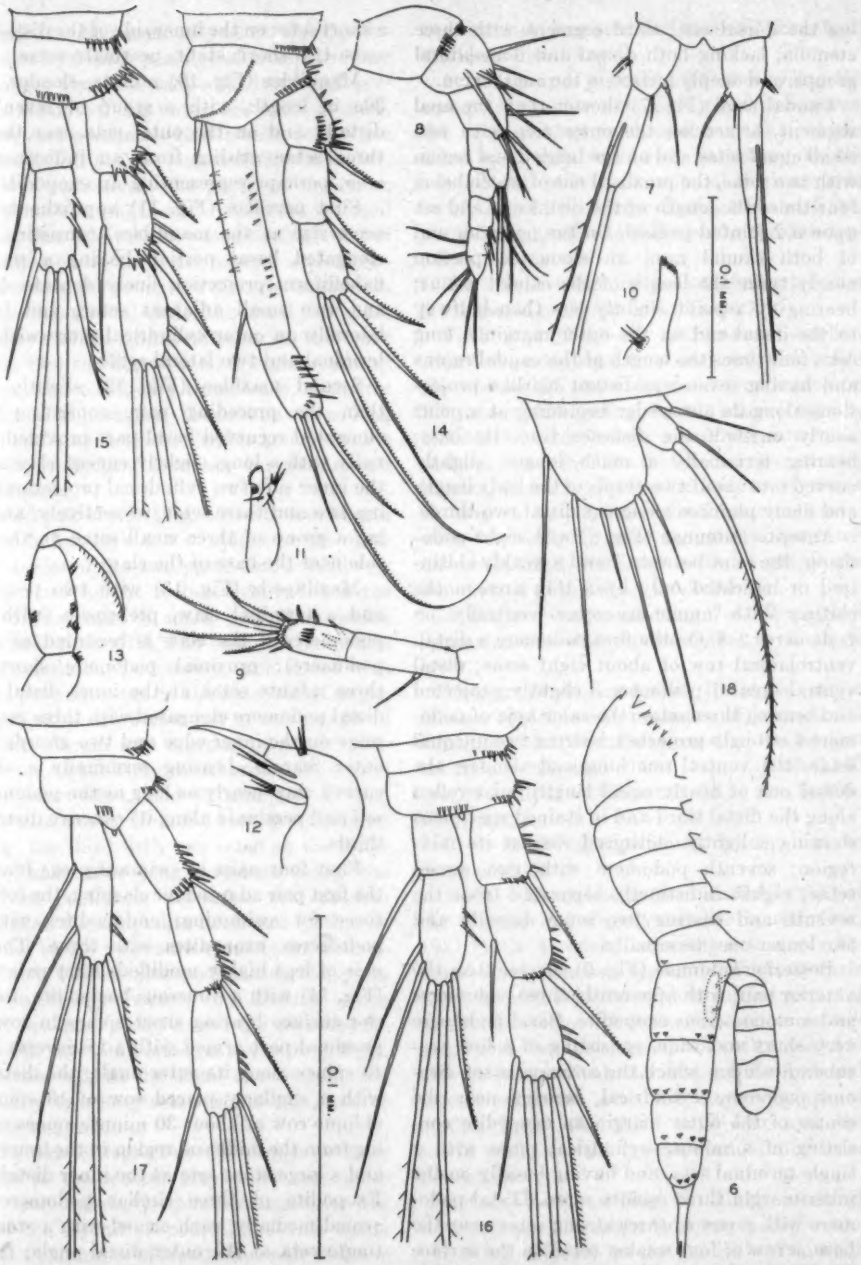
Pholetiscus orientalis, n. sp.

Type material, consisting of more than 70 individuals representing both sexes, from the gill chambers of three species of brachyurans, *Sesarma eumolpe* de Man, *Sesarma taeniolatum* White, and *Sesarma palawanense* Rathbun (the specific determination of the last-named being somewhat uncertain), collected on August 6, 1945, at Tarakan, Dutch Borneo. Holotype, female, U.S.N.M. no. 82266; allotype, U.S.N.M. no. 82268; 30 paratypes including both sexes, U.S.N.M. nos. 82267 and 82269–82293; the remaining paratypes in the author's collection.

Female.—Body moderately slender. Length about seven times the greatest width. Metasome slightly shorter than urosome, both somewhat cylindrical but tapering posteriorly. Cephalic and first thoracic segments approximately equal to the length of the second, third, and fourth thoracic segments combined, well developed laterally, without setae. Rostrum minute, rounded anteriorly and unarmed.

First segment of the 6-segmented thorax usually only indistinctly separated from the head, the dorsum being shorter than that of any of the succeeding thoracic segments. Second, third, and fourth thoracic segments similar to each other in size and shape. Fifth segment with dorsum somewhat shorter than that of the fourth, not telescoped with adjacent dorsa (Fig. 6). Sixth segment of the thorax (genital), bearing a single ovisac at the midventral anterior margin, longer than any of the first five segments and having dorsally a weak transverse division. First four thoracic segments without setae; segment 5 with a vertical row of 6 minute setae (forming a ctenidium) near the posterior lateral margin; segment 6 with a vertical row of four ctenidia each composed of five or six setae on both sides.

Abdomen 3-segmented, third segment slightly shorter than the second and first but all shorter than the sixth thoracic. First abdominal segment with five ctenidia on both sides; second segment with four ctenidia, lack-



FIGS. 6–18.—*Pholetiscus orientalis*, n. sp., female: 6, Body segments; 7, caudal rami; 8, anterior antenna; 9, posterior antenna; 10, mandible; 11, first maxilla; 12, second maxilla; 13, maxilliped; 14, first leg; 15, second leg; 16, third leg; 17, fourth leg; 18, fifth leg.
All figures drawn with the aid of a camera lucida. The shorter of the two scales applies only to Fig. 7; the longer to Figs. 8–18 and 20–24.

ing the dorsal one; third segment with three ctenidia, lacking both dorsal and dorsolateral groups, and deeply incised in the anal region.

Caudal rami (Fig. 7) shorter than the anal segment, armed on the outer side with two small equal setae and on the inner distal region with two setae, the proximal one of which being four times the length of the distal one and set upon a 2-jointed pedicel. On the posterior end of both caudal rami an elongated portion nearly twice the length of the caudal ramus; bearing at a point slightly less than halfway to the distal end on the outer margin a long seta, four times the length of the caudal ramus and having seven equidistant hairlike projections along its outer edge beginning at a point nearly one-half the distance from its base; bearing terminally a much longer, slightly curved seta about two-thirds of the body length and finely plumose along the distal two-thirds.

Anterior antennae (Fig. 8) with eight podomeres, the joint between 7 and 8 weakly chitinized or indicated only by a thin area in the chitin. With numerous setae ventrally on podomeres 2–8. On the first podomere a distal, ventrolateral row of about eight setae; distal ventral area of podomere 3 slightly projected and bearing three setae; the same area of podomere 4 strongly projected, bearing two unequal setae, the ventral one long and slender, the dorsal one of nearly equal length but swollen along the distal third and in stained specimens showing a lightly chitinized ring at its midregion; seventh podomere with two dorsal setae; eighth indistinctly separated from the seventh and bearing two setae dorsally and two longer ones terminally.

Posterior antennae (Fig. 9) shorter than the anterior pair, with apparently three podomeres and a monomerous exopodite. Basal podomere very short and wide, consisting of a low protuberance upon which the antenna is set. Second podomere cylindrical, bearing near the center of the outer margin an exopodite consisting of a minute cylindrical piece with a single terminal seta, and having basally on the inner margin three minute setae. Distal podomere with a row of three strong setae near the base, a row of four weaker setae on the surface of the distal half, and an arched row of 12 smaller setae along the distal margin; terminally a row of four strongly developed, pectinate setae and laterally at both ends of the row a short seta; on the inner side of the distal podomere two short, stout, pectinate setae.

Mandibles (Fig. 10) minute, slender, about 30μ in length, with a group of seven teeth distally and on the outer side near the base three setae arising from an indistinct oval area, perhaps representing an exopodite.

First maxillae (Fig. 11) approximately the same size as the mandibles, consisting of an elongated basal portion having a terminal, flabelliform projection finely dentate distally and two small adjacent setae, and bearing laterally an outer cylindrical piece with three terminal and two lateral setae.

Second maxillae (Fig. 12) slightly larger than the preceding pair, consisting of an elongated recurved basal part provided terminally with a long, slightly curved claw and on the inner side two cylindrical projections bearing two and three setae, respectively, and having a group of three small setae on the outer side near the base of the claw.

Maxillipeds (Fig. 13) with two podomeres and a terminal claw, prehensile (with three podomeres if the claw is regarded as a true podomere); proximal podomere short with three minute setae at the inner distal angle; distal podomere elongated with three groups of setae on the inner edge and two groups on the outer margin, bearing terminally a slender, curved claw nearly as long as the podomere itself and pectinate along its concave distal two-thirds.

First four pairs of swimming legs biramous, the first pair adapted for clasping, the following three for swimming; endopodites with two podomeres, exopodites with three. The fifth pair of legs highly modified. First pair of legs (Fig. 14) with a dimerous basipodite, its anterior surface bearing short spines in rows; the proximal part armed with a transverse row of 10 spines along its outer angle; the distal part with a similarly placed row of 13 spines, an oblique row of about 30 minute spines extending from the midbasal region to the inner angle, and a large stout seta at the inner distal angle. Exopodite of three similar podomeres, unarmed medially, each armed with a stout pectinate seta at the outer distal angle; the first podomere with two rows of five and eight setae respectively distally and two isolated setae proximally along its outer margin; the second and third podomeres with three setae along

the outer margin; terminally on the third podomere a row of three prominent setae, the inner two longer than the exopodite itself and pectinate medially, the outer one half as long, stouter, and pectinate. Endopodite nearly one and one-half times the length of the exopodite, with two podomeres; the proximal podomere three times the length of the distal one, armed on the outer side with two longitudinal rows of five setae and on the inner margin with a central row of eight setae and a single larger seta near the inner distal angle; the distal podomere with a row of six spiniform setae on the outer margin, two smaller setae at the distal end of the row, and terminally three setae, the outer one stout and pectinate, the middle one as long as the endopodite itself, slender and pectinate along its midlength, the inner one slender and much shorter.

Second pair of legs (Fig. 15) with a dimerous basipodite having a row of spines at the outer distal angles of the two parts and a third row near the base of the endopodite; between the bases of the rami a small projection which stains brilliantly with acid fuchsin. Exopodite with three similar podomeres, each armed with a stout pectinate seta on the outer distal angle; the first podomere with a row of three setae on the outer margin and a group of seven spiniform setae on the outer distal angle; the second with similar setae, and in addition a long, slender seta arising from the center of the inner margin; the third with two setae on the outer margin and three long terminal setae, the outer one pectinate, the other two slender, longer than the exopodite itself and feathered, the inner of the two more sparsely so. Endopodite with two similar podomeres, the proximal one slightly shorter; both bearing a long seta at the inner distal angle; the distal podomere with two small setae on the outer margin, a pectinate seta at the distal outer angle, and terminally two long setae which are plumose in the distal half.

Third pair of legs (Fig. 16) similar in most respects to the second. Exopodite with three similar podomeres, the setal arrangement like that of the second exopodite, but with variations in the number of small setae and with the addition of a seta at the inner distal angle of the third podomere. Endopodite with two podomeres, similar to those of the second endopodite but with the addition of a long seta between the inner terminal seta and the seta at the inner distal angle.

Fourth pair of legs (Fig. 17) resembling the second. Exopodite with three equal podomeres, the setal arrangement similar to that of the third exopodite, but with variations in the number and with the deletion of the inner seta on the second podomere. Endopodite with two podomeres, similar to those of the third endopodite.

The setal arrangement of swimming legs 1–4 is expressed numerically in Table 2.

Fifth legs (Fig. 18) uniramous, lamellar, with two podomeres, the basal one with a single seta on the outer corner and expanded on the inner side into a broad lamina bearing terminally a row of six setae, the outermost and the third from the midline being distinctly shorter than the others which are nearly twice as long as the lamina; distal podomere oval with two unequal setae terminally, the inner one more than three times the length of the lamina and plumose on its distal half.

A single ovisac containing 7–11 eggs, each approximately 50μ in diameter, in a single layer.

Measurements based upon 10 females are as follows: Total length exclusive of setae, 0.637 mm (0.588–0.705 mm); greatest width (at first thoracic segment), 0.094 mm (0.080–0.110 mm); length of caudal setae, 0.431 mm (0.426–0.514 mm).

Color in living specimens transparent to opaque white.

Male.—General body form similar to that of the female, but slightly smaller in size (Fig. 19). Sixth thoracic segment not distinctly longer than adjacent segments. Fifth thoracic segment with a posterior dorsolateral group of minute setae on both sides. Sixth thoracic segment with two linear groups of such setae. Abdomen 4-segmented, the sides of the first and second segments with five linear groups of minute setae, the third with four and the fourth with two such groups. Caudal rami as in the female.

Anterior antenna (Fig. 20) highly modified for clasping, with eight podomeres (the number being difficult to distinguish) with their joints strongly chitinized; first podomere without setae; second with four spiniform setae arising from the outer side, and four slender setae situated on a slight projection on the

inner side; third and fourth podomeres very short with several setae on the inner margins; fifth very large and swollen along the outer proximal angle with several setae on the inner margin, some on conical projections; sixth concave on inner margin from which arise two pairs of long setae and one or more stout knoblike ridges; seventh with inner surface half the length of the outer edge and bearing at the distal angle a group of filamentous setae; eighth podomere terminally pointed and clawlike, with six setae arising from its convex outer edge; the whole arranged so that the tip of the eighth podomere may be brought in contact with the inner distal angle of the fifth.

Second antennae, mouth parts, and first and second legs similar to those of the female. Third pair of legs (Fig. 21) with basipodite and exopodite like those in the female, but endopodite with three podomeres instead of two; the first armed with a long seta at the inner distal angle; the second slightly longer, bearing three short, stout setae near the middle of its outer margin and a falciform projection (its articulation difficult to distinguish) at the inner distal angle; the third podomere distinctly smaller, about half the length of the first, the joint separating it from the second often not strongly chitinized, and bearing terminally two long setae which are sparsely plumose distally.

Fourth pair of legs like that of the female but usually lacking the two inner distal setae, rarely only one, on the second podomere of the endopodite.

The setal arrangement of swimming legs 1–4 is shown in Table 2.

TABLE 2.—ARRANGEMENT OF SPINES AND SETAE ON SWIMMING LEGS 1–4 OF PHOLETISCUS ORIENTALIS, N. SP.

Swimming leg		Female			Male		
First pair	exopodite	1,0	1,0	4	1,0	1,0	4
	endopodite	0,1	3		0,1	3	
Second pair	exopodite	1,0	1,1	4	1,0	1,1	4
	endopodite	0,1	4		0,1	4	
Third pair	exopodite	1,0	1,1	5	1,0	1,1	5
	endopodite	0,1	5		0,1	3,1	2
Fourth pair	exopodite	1,0	1,0	5	1,0	1,0	5
	endopodite	0,1	5		0,1	3	

See Table 1 for explanation of numbers.

Fifth legs of the male (Fig. 22) very much smaller than in the female, reduced to a low lamellar ridge with three setae, the outermost the longest and set upon a cylindrical base, the innermost the shortest. The two internal setae are borne upon a low projection separated by a groove from the base of the external seta. Medially to the three setae a slightly projecting area which usually is nude, but which in two specimens bore a single seta.

Spermatophore (Fig. 23) elongate, oval, attenuated, and recurved at the anterior end.

Measurements of 10 males: Total length exclusive of setae, 0.592 mm (0.514–0.646 mm); greatest width (first thoracic segment), 0.092 mm (0.088–0.102 mm); length of caudal setae, 0.444 mm (0.411–0.480 mm).

Color in living specimens like that of the female.

Remarks.—Pholetiscus orientalis differs from the only other known species of the genus, *P. wilsoni* (Pearse), in the following respects:

FEMALE:

- Anterior antennae with eight podomeres instead of six.
- Presence of an exopodite on posterior antennae.
- Differences in setal arrangement on swimming legs 1–4 (compare the numerical tabulations in Tables 1 and 2).
- Two long terminal setae on caudal rami arise from common base instead of separately (compare Figs. 5 and 7).

MALE:

- Differences in armature of the endopodite of the third swimming leg (compare Figs. 4 and 21).

One female copepod was found in which all rami of the swimming legs were normal except the exopodite of the left third leg (Fig. 24) which had only two podomeres instead of three, with the setal arrangement 0, 0, and 5.

The number of small setae in groups on the thoracic legs is subject to variation, and for that reason it is doubted whether giving formulas of all setae, large and small, is particularly useful. Such variation exists, for example, in the number of setae along the inner margin of the first thoracic endopodite, which was found to vary from six to nine with the usual number of eight.

When the copepods were placed in a watch glass of sea water, they swam about actively, often in pairs, a male clasping the terminal setae of the caudal rami of a female by means of its anterior antennae.

The food of *P. orientalis* consists partly at

TABLE 3.—INCIDENCE OF PHOLETISCUS ORIENTALIS IN HOST CRABS AT TARAKAN, DUTCH BORNEO

Host crab	Number of specimens examined	Number positive	Number negative	Largest number found in any individual crab	Average number of copepods per positive crab
Sesarma eumolpe de Man:					
Females	24	20	4	27	5.4
Males	24	15	9	34	6.7
Total	48	35	13		6.0
Sesarma taeniolatum White:*					
Females	11	5	6	7	5.0
Males	13	5	8	7	3.4
Total	24	10	14		4.2
Grand total	72	45	27		5.0

* Included in this category are a few individuals of *Sesarma palawanense* Rathbun, not distinguished from *taeniolatum* at the time of collection.

least of diatoms of the *Pinnularia* type and blue-green algae, both of which were frequently observed in the alimentary tract of mounted specimens.

The incidence of *P. orientalis* in host crabs at Tarakan is shown in Table 3.

The crabs were collected in a marshy area a quarter of a mile west of the town of Tarakan, located on Tarakan Island in the delta region formed by the Sungei Sesayap. The marsh is periodically flooded by tidal water from Batagau Strait. Some crabs were found in water-filled depressions, others were running about on moist ground under debris of wooden shingles and rotting palm fronds.

In all three species of host crabs and in both sexes unidentified nematodes and diperous larvae were frequently found in the gill chambers along with the copepods.

DISCUSSION

The genus *Pholetiscus* mihi is related to *Cancrincola* Wilson, 1913, and both may be included in the family Canthocamptidae *sensu lato*. However, if the family is used in the restricted sense, as in Monard's synoptic work on the harpacticoids (1927), then it properly would include only *Pholetiscus*, *Cancrincola* being removed to the Ameiridae.

The two genera are well defined, both morphologically and geographically, *Cancrincola* being found in the Caribbean and Gulf of Mexico area, and *Pholetiscus* in Borneo and Japan. It seems probable that future investiga-

TABLE 4.—DISTINCTIVE CHARACTERS SEPARATING THE GENERA CANCRINCOLA AND PHOLETISCUS

	Character	*Cancrincola*	*Pholetiscus*
Female	Rami of legs 1–4	Endopodite of first with 2 podomeres; all others with 3.	Endopodites with 2 podomeres; exopodites with 3.
	Number of abdominal segments	4	3
	Number of aesthetasks	1 or 2	None
	Distal podomere of fifth leg	With 4 or 5 terminal setae.	With 2 terminal setae.
	Terminal setae on caudal ramus*	1 long curved seta plus other small ones.	1 long curved seta, another $\frac{1}{4}$–$\frac{1}{3}$ as long, plus other small ones.
	Mandibular palp*	Cylindrical, tipped with about 4 slender setae.	Reduced to only 1–3 small setae.
Male	Number of abdominal segments	4	4
	Anterior antennae	With 8 podomeres, moderately prehensile.	With 3–8 podomeres, strongly prehensile.
	Number of aesthetasks	1	None
	Rami of legs 1–4	Endopodite of first with 2 podomeres; all others with 3.	Endopodites of first, second, and fourth with 2 podomeres; endopodite of third with 3 podomeres; all exopodites with 3.

* True of male also.

tions will greatly increase the geographical range of these genera. Both genera occur in the gill chambers of marsh crabs, especially those of the genus *Sesarma*, commonly found in the vicinity of river deltas.

The two genera are readily separated by making the comparisons shown in Table 4.

The harpacticoid copepods at present known to inhabit the gill chambers of crabs comprise four species belonging to two distinct though related genera, namely, *Cancrincola jamaicensis* Wilson, 1913, *C. plumipes* Humes, 1941, *Pholetiscus wilsoni* (Pearse, 1930), and *P. orientalis* mihi. The two species of *Pholetiscus* may be distinguished from those of *Cancrincola* and from each other by the following key:

1. Female 2
   Male 4
2. Endopodite of first leg with 2 podomeres, all others with 3; distal podomere of fifth leg with 4 or 5 terminal setae ..... *Cancrincola*
   Endopodites all with 2 podomeres; distal podomere of fifth leg with 2 terminal setae ..... *Pholetiscus* 3
3. With exopodite on posterior antennae; 2 long terminal setae on caudal ramus arising from common base ..... *P. orientalis*
   Without exopodite on posterior antennae; 2 long terminal setae on caudal ramus arising separately ..... *P. wilsoni*
4. Endopodites of second, third, and fourth legs with 3 podomeres ..... *Cancrincola*
   Endopodites of second and fourth legs with 2 podomeres, third with 3 ... *Pholetiscus* 5
5. Three stout spines near base of falciform projection on second podomere of third endopodite ..... *P. orientalis*
   One minute spine near base of falciform projection on second podomere of third endopodite ..... *P. wilsoni*

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PROCEEDINGS OF THE ACADEMY

408TH MEETING OF BOARD OF MANAGERS

The 408th meeting of the Board of Managers, held in the Cosmos Club, April 14, 1947, was called to order at 8 P.M. by the President, Dr. WALDO L. SCHMITT. Others present were: H. S. RAPPLEYE, F. M. SETZLER, W. N. FENTON, H. B. COLLINS, JR., W. W. DIEHL, J. S. WADE, L. E. YOCUM, W. A. DAYTON, M. A. MASON, A. O. FOSTER, C. L. GARNER, C. L. GAZIN, and, by invitation, G. P. WALTON.

The President announced the appointment of A. T. MCPHERSON and W. W. RUBEY to the Legislative Committee, authorized at the March 17 meeting of the Board, with Dr. MCPHERSON as Chairman. Additional appointments to this Committee are expected to be made in the near future.

The Chairman of the Meetings Committee, G. P. WALTON, announced that Prof. J. B. SUMNER, biochemist of Cornell University, had been scheduled to speak at the May meeting of the ACADEMY on the work for which he was recently awarded a Nobel Prize.

Ten persons were elected to membership in the ACADEMY.

The Chairman of the Anniversary Committee, F. M. SETZLER, reported an informal consideration of plans for celebrating the 50th anniversary of the founding of the ACADEMY. The date for such a celebration was discussed, and informal show of hands indicated a majority of the Board in favor of February 18, 1948. The desirability of holding a subscription dinner was discussed as one of the ways in which the anniversary might be observed.

The Treasurer, Mr. RAPPLEYE, announced an increase in returns from investments in the Washington Sanitary Improvement Co. He also announced that 30 new subscriptions for the JOURNAL had been obtained from Russian sources, with a possibility of 5 more.

The Senior Editor, Dr. FENTON, reported the prospect of devoting one issue of the JOURNAL to the three Academy Award winners for 1947.

The President presented his ideas on the desirability of appointing a historian for the ACADEMY, or a committee, to look into various past activities and in particular to ferret out any unconsummated actions indicated in the Board's past records.

The President also announced a Science Fair, organized by the teachers of the District of Columbia secondary schools and sponsored by the scientific societies of Washington, to be held during the week May 19 through May 23 in the Department of Commerce Building.

The meeting adjourned at 9:15 P.M.

NEW MEMBERS OF THE ACADEMY

There follows a list of persons elected to membership in the ACADEMY, by vote of its Board of Managers, since June, 1945, who have since qualified as members in accordance with the bylaws. The bases for election are stated with the names of the new members.

RESIDENT

Elected October 15, 1945

WILLIAM HARLEN GILBERT, Jr., anthropologist, Library of Congress, in recognition of his contributions to knowledge of social organization in studies of the Cherokee Indians and of the caste systems of India and Ceylon.

CHARLES LEWIS GORDON, chemist, National Bureau of Standards, in recognition of his contributions to methods of solution of refractory materials, particularly at elevated temperature and pressures, and to analytical procedures for such materials.

FRANK WILBUR SCHWAB, chemist, National Bureau of Standards, in recognition of his contributions to the chemistry of analytical reagents and pure substances, and to knowledge of the properties of benzoic acid which makes it possible to use the freezing temperature of this substance as a fixed point for precision resistance thermometry.

Elected November 9, 1945

HOMER G. BARNETT, anthropologist, Smithsonian Institution,[1] in recognition of his studies of the processes of cultural change, and of the ethnology of the Northwest Coast Indians.

SCOTT ELLSWORTH FORBUSH, physicist, Navy Department, in recognition of his contributions to geomagnetism, in particular for his investigations of cosmic radiation and its relation to geomagnetism.

VICTOR HICKS, physicist, Navy Department, in recognition of his services in the field of radiology; and his contributions during the war to the research program of the Bureau of Ordnance, Navy Department.

[1] Dr. Barnett has since returned to the University of Oregon.

Elected January 14, 1946

CHARLES J. CLIFFORD, mathematician, U. S. Coast and Geodetic Survey, in recognition of his work in the processing and analysis of geodetic-survey records particularly with reference to precision leveling and the study of earth movement as revealed by repeated levelings.

ROBERT C. DUNCAN, physicist, Naval Ordnance Laboratory, in recognition of his contributions to the development of under-water ordnance and naval warfare.

Elected February 18, 1946

EDWARD E. CLAYTON, botanist, Bureau of Plant Industry, Soils, and Agricultural Engineering, in recognition of his contributions in the fields of vegetable diseases and tobacco diseases, especially disease resistance.

FREDERICK J. HERMANN, botanist, Bureau of Plant Industry, Soils, and Agricultural Engineering, in recognition of his research work in American botany, particularly in the taxonomy and phytogeography of North American phanerogams, and more especially in the difficult genera *Juncus*, *Carex*, and *Astragalus* and in the family Leguminosae.

HENRY A. RUTHERFORD, chemist, Milton Harris Associates, in recognition of his contributions to the chemistry of fibers, in particular his work on the oxidation of wool and cellulose.

ROBERT SIMHA, chemist, National Bureau of Standards, in recognition of his contributions to the physical chemistry of high polymers and in particular his researches on the theories of viscosity, elasticity, and flow and the kinetics of polymerization.

BENNETT T. SIMMS, veterinarian, Bureau of Animal Industry, in recognition of his contribution to parasitology and infectious diseases of domestic animals, especially his solution of the problem of salmon poisoning of dogs in the Pacific Northwest.

BRUCE L. WILSON, physicist, National Bureau of Standards, in recognition of his work in improving methods for the calibration of dynamometers, strain gages, and machines for testing mechanical properties.

Elected May 13, 1946

DORIS H. BLAKE, entomologist, in recognition of her work on the taxonomy of beetles, particularly of the family Chrysomelidae.

HENRY W. HEMPLE, geodesist, U. S. Coast and Geodetic Survey, in recognition of his contributions to the science of practical geodesy

and in particular for his improvements in instrumental methods and the development of the horizontal survey nets of the United States.

HENRY A. JONES, botanist, Bureau of Plant Industry, Soils, and Agricultural Engineering, in recognition of his contributions in the fields of horticulture and genetics, in particular the genetics of *Allium cepa*.

CLARENCE A. REED, botanist, Bureau of Plant Industry, Soils, and Agricultural Engineering, in recognition of his contributions to horticulture, particularly his investigations in hybridization of nut trees.

FREDERICK J. STEVENSON, botanist, Bureau of Plant Industry, Soils, and Agricultural Engineering, in recognition of contributions in plant genetics, in particular his studies on inheritance of resistance to diseases in cereals and potatoes.

Elected December 16, 1946

BAILEY E. BROWN, botanist, Summers Fertilizer Co., Inc., Baltimore (resident of Washington), in recognition of his work on the fertilizer requirements of different soil types and especially on the fertilization of potatoes.

EDWARD U. CONDON, physicist, National Bureau of Standards, in recognition of his contributions to theoretical physics, particularly quantum mechanics.

ROMAN F. GELLER, ceramist, National Bureau of Standards, in recognition of his work on clays, pottery, insulators, and refractories.

ARTHUR E. RUARK, physicist, Applied Physics Laboratory, Johns Hopkins University, in recognition of his outstanding contributions in the field of physics.

MERLE A. TUVE, physicist, Department of Terrestrial Magnetism, Carnegie Institution of Washington, in recognition of his outstanding contributions in the field of physics.

Elected January 13, 1947

MYRON S. ANDERSON, chemist, Bureau of Plant Industry, Soils, and Agricultural Engineering, in recognition of his contributions in the field of soil chemistry, in particular of his researches on soil colloids.

J. F. GATES CLARKE, entomologist, Bureau of Entomology and Plant Quarantine, in recognition of his contributions on the taxonomy of the Microlepidoptera.

HERBERT G. DEIGNAN, biologist, U. S. National Museum, in recognition of his contributions to knowledge of the ornithology of southeastern Asia, especially Siam, on which subject he is the outstanding American authority.

JOSEPH A. EWAN, botanist, Bureau of Plant Industry, Soils, and Agricultural Engineering, in recognition of his monographic studies of *Delphinium* and other important genera of vascular plants; his floristic investigation in California and Colorado with particular emphasis upon the correlation of the flora with geography; his bibliographic and historical essays; and his broad background and deep interest in the whole field of biology.

EARL D. FOWLER, botanist, Bureau of Plant Industry, Soils, and Agricultural Engineering, in recognition of his work in soil investigations, survey, and classification.

GEORGE WASHINGTON IRVING, Jr., chemist, Bureau of Agricultural and Industrial Chemistry, in recognition of his work on pituitary hormones and extensive research on plant and animal enzymes and proteins.

RONALD MUNRO WILSON, engineer, U. S. Geological Survey, in recognition of his contributions to the art of surveying and in particular for his development of the photoalidade in plane table operations.

NONRESIDENT

Elected January 14, 1946

EDUARDO C. CABALLERO, entomologist, Instituto de Biología, Casa del Lago, Chapultepec, Mexico, in recognition of his contributions to knowledge of the helminth fauna of Mexico.

Elected February 18, 1946

FREDERICK K. SPARROW, botanist, University of Michigan, in recognition of his contributions on aquatic phycomycetes.

Elected January 13, 1947

NORMAN C. FASSETT, botanist, Harvard University, in recognition of his contributions to the knowledge of the flora of Wisconsin, his phylogeographic studies of the North American flora, especially of aquatic species, and his successful advocacy of the importance of mass collection in taxonomic researches.

LEWIS B. KELLUM, geologist, University of Michigan, in recognition of his contributions to the stratigraphy and structure of Mexico.

ALEXANDER HANCHETT SMITH, botanist, University Museums, University of Michigan, in recognition of his contributions to the taxonomy and cytology of the Agaricales.

C. L. GAZIN, *Secretary.*